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ICTs DIFFUSION TRAJECTORIES AND ECONOMIC DEVELOPMENT – AN EMPIRICAL EVIDENCE FOR 46 DEVELOPING COUNTRIES

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Abstract. In economic theory, technology is treated as crucial factor contributing significantly to economic development. In seminal works of Schumpeter [1934, 1947], Baumol [1986], Gerschenkron [1962] or Abramovitz [1986], the emphasis on the role of technological progress in process of economic development is put extensively. Along with the previous, there emerged theoretical and empirical works on technology diffusion (i.e. Rogers 1962, Geroski 2000), where the dynamics of the process is considered. Temporarily, the spread on new information and communication technologies (ICTs) is massive. The objectives of the study are twofold. Using panel data we analyze the diffusion trajectories of ICTs in developing countries, and we assess the dynamics of the process. Secondly, we hypothesize on existence quantitative links between ICTs adoption and economic development. The time framework is set for period 2000-2011. Statistical data are derived from World Telecommunication/ICT Indicators Database 2012, World Development Indicators 2013 and Human Development Report 2013.

Keywords: ICTs, diffusion, economic development, developing countries, S-shaped curve.

1 Introduction.

New information and communication technologies (ICTs) are internationally recognized as an important source of fostering development process among world countries, contributing significantly to economic development and growth. The observed dynamic of adoption of ICTs in world economies is astonishingly high, and is thought to cause huge changes in overall country`s economic performance. This is mainly due to its unique features that change the way of doing business, open new possibilities for setting up a business, or just enhance increases in human and social capital. At the same, ICTs can be adopted fast and at low cost, requiring minimal capabilities for their usage. Case-studies from all around the world show that ICTs are evidently of crucial importance for economic and social development [see e.g. reports of infoDev.org; UNCTAD; globalvoicesonlone.org; ict4d.org.uk]. There also exists an exhaustive literature explaining role of ICTs in development fostering [see i.g. "ICT for development. Improving Policy Coherence" OECD 2010]. However, we still experience lack of quantifiable proof that wide in-country adoption of ICTs is a driving factor of economic development. From pure scientific and economic policy perspective the deep insight into the existing links between ICTs implementation and economic development remains of crucial importance.

2 Technology diffusion – theoretical outline.

2.1 Definitions and concepts.

Related literature, considering theoretical and empirical aspects of technology diffusion is vast and exhaustive. Qualitative and quantitative explanations of technology diffusion process are deeply rooted in the evolutionary paradigm of Charles Darwin [1859] and his pioneering work on natural growth and spatial diffusion of species. Darwin [1859] predicts the unique ability of species to multiply achieving exponential growth rates in time, and in competition. The concept was then adjusted for the use on the field of economic sciences, implying a basic assumption that "species" can be defined as any variable (like i.g. Gross Domestic Product, technology or product) which tends to grow in time.
A critical introduction of technology to economic sciences was done by Joseph Schumpeter and his seminal works [1934, 1947]. Classical Schumpeterian analysis of technological change, perceived it a process of constant destruction of "old" by the "new", and the concept of "creative destruction" was supposed to lead to constant disequilibrium and reinforces progress. Notwithstanding innovative, the Schumpeterian analysis did not receive much attention, mainly due to its highly theoretical, strict and simplifying assumption on linearity of

the process, and ignorance for the distinction between invention and innovation.

In late 50`s of XX century, a pervasive contribution on the field was made. Broad studies of the phenomenon of technological diffusion over countries (as well as within them) was studied and resulted in elaboration of highly theoretical "epidemic models[1]" of diffusion. Many claimed [see works of Griliches 1957, Mansfield 1968, Romeo 1977, Davis 1979, Metcalfe 1988, Karshenas and Stoneman 1995, Stoneman 2001, 2005], these models to explain fully and correctly the process of step-by-step adoption of new technologies by societies. This innovative approach, however, had many limitations and omissions. The concept is build on the strict assumption that diffusion and speed of adoption by potential users is highly limited by lack of information on the possibilities of new technologies (products) availability and poor skills and knowledge on how to use the "new technology". In effect, the approach was "blind" to the dynamics of the process in time, totally ignored the societal, demographical, cultural, educational, institutional prerequisites which conditioned the rate of adoption, and its effective usage.

Nowadays, most of theoretical and empirical works on technology diffusion refer to ideas of Everett Rogers and his seminal work "Diffusion of Innovation" [Rogers, E., 1962, Diffusion of Innovation. Free Press]. His model of technology diffusion is widely applied in political sciences, economics, public health policies, history or education. He defines technology as "design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcomes" [Rogers 1962, p.6, while diffusion refers to: "process by which an innovation (*technology – author`s note*) is communicated through certain channels over time among members of a social system" [Rogers 1962, p.10]. The mechanism of technology diffusion encompasses 4 elements: innovation (defined as "an idea, practice, or project that is perceived as new (…) [Rogers, 1962, pp.12], communication channels ("process in which participants create and share information", [Rogers, 1962, pp.5], time (time in behavioural studies is perceived as an element determining the strength of the process) and social system ("a set of interrelated units", [Rogers, 1962, pp.23]. The communication channels which enable the process are

[1] Concept of "epidemic models" was originally derived from medical sciences. The "epidemic" term referred to spontaneously and uncontrolled spread of diseases.

recognized as: knowledge, persuasion, decision, implementation and confirmation. The *"knowledge"* element is highly influenced by general socio-economic characteristics of an individual; while the *"persuasion"* phase is mainly determined by the cost-benefit analysis results that an individual shall do, and assessment of relative advantages which are presumed to happen while introducing given innovation. Following the above, the process is highly depended on functioning of societal system, where society`s members give decisions[2] on adoption or rejection of usage of given innovation individually.

2.2 S-shaped curves of technology diffusion – estimating dynamics of the process.

In literature, S-shaped curves are often treated as kind of "mental model" [Geroski 2000], which defines a specific way of thinking about technology diffusion. It offers a theoretical specification for capturing the dynamics of the diffusion process in time, leading to identification of unique growth phases. Such approach impacts powerfully modes of analysis, which can be either stimulating or limiting. The adoption of logistic models and S-shaped curves to practical applications was initiated by Thomas Malthus in his work *An Essey on the Principle of Population*. In 1825, Benjamin Gompertz introduced the idea of law of natural growth to studies on population and mortality. The concept was then firstly mathematically formalized in 1838 by Pierre-Francois Verhulst, who developed a logistic growth formula to describe quantitatively the process of natural growth. His work was then followed by Raymond Pearl [1924], Alfred Lotka [1926] (elaboration of predator-prey equation). The logistic models were then gradually adopted in empirical works on technological progress and substitution. The pioneering works on the field were introduced by Griliches [1957, 1961], Mansfield [in 1960s], or Rogers [1962].
Mathematical background for the analysis of S-shaped curve phenomenon are single growth models, originated from the Ordinary Differential Equations [Meyer *et al.* 1999]. The equation applied for description of technologies reveal continuous patterns of growth in time.

2 The decisions are not collective, but rather individual.

The simple growth model (with *e* introduced), can be formalized as:

$$P(t) = \beta e^{\alpha t} \tag{1}$$

where *P(t)* specifies growing variable, *t* - time, and α - growth rate. The equation (1) imposes no limits to growth, unless the conditions are changed. But, the idea of limits to growth is quite familiar. Due to many restrictions and barriers different variables cannot grow infinitely. It occurs that negative signals from environment limit growth, and in effect the process slows down "producing" the S-shaped (sigmoid) curve [Meyer *et al.* 1999]. In real world, very few – if any – systems remain unbounded, which brings the necessity of simple modification of the formula (1), by posing the limits (i.e. upper asymptote) arbitrary. The growth rates begin as exponential, but then in time, start to slow down (potentially reaching zero) as the variable value approached the upper limit defined by κ. If the $(P(t) \rightarrow \kappa)$ the sigmoid growth curve is revealed. By adding to the standard growth model the "slowing factor" defined as:

$$\left(1 - \frac{P(t)}{\kappa}\right) \tag{2}$$

where the κ - parameter stands for the upper limit of growth, we estimate logistic growth model again.
To formalize the above, let`s rewrite the simple logistic growth model (SLM) in an analytical form:

$$P(t) = \frac{\kappa}{1+exp\,(-\alpha(t-\beta))} \qquad (3),$$

or alternatively:

$$P(t) = \frac{\kappa}{1+e^{-\alpha t-\beta}} \qquad (4).$$

To specify the S-shaped curve, the 3 parameters (α,β,κ) need to be estimated. The κ imposes the upper limit of growth (upper asymptote of

curve); the α - specifies the “steepness” (“width”) of the curve (approximates the growth rates), and it indicates time (i.e. years) needed for a variable to grow from 10% of saturation to 90% (also named “specific/characteristic duration”); and the - β - explains the “midpoint” of the curve which stands for the time when the curve reaches the 0,5κ (is shows the symmetry of the curve).
The visualization of the logistic model is cleared in Fig.1. (see below). It shows the idealized S-shaped patterns with clearly distinguished phases of growth. The curve is cumulative in his nature, meaning that any point of curve stands for the height that presents “saturation” – share of population which has adopted the innovation (technology).

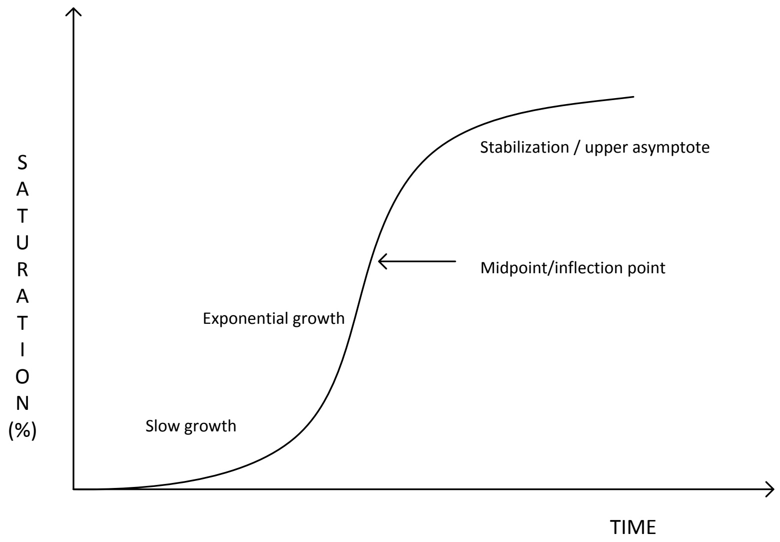

Fig. 1. S-shaped curve and phases of diffusion (Source: author`s elaboration).

In the S-shaped curve 4 characteristic phases of growth are easily distinguishable. The first (initial) phase (Ph1) stands for the very prime phases of diffusion where the adoption rate is slow and gradual. Afterwards occurs the second phase (Ph2) of exponential growth, where the adoption rates are rapid and the diffusion of technology is massive. When saturation reaches certain level, the growth slows down, and after passing the inflection point, entering the slow growth path of the third phase(Ph3). Finally, occurs the stabilization phase (Ph4) approximated by the κ, when the growth potentially stops. For the analytical usefulness the time and level of saturation are of crucial importance. It indicates changes, predicting the emergence of new or substitute technology (innovation).

3 Why developing nations need ICTs?

3.1 Technological change and economic development.

The notion of technology is broad, complex and combines quite a multitude of features. If can refer strictly to the idea of productive activities, some basis for production [Metcalfe, 2009], but also can refer to some organizational and management matters, and does not have to refer strictly to productive knowledge. From economic perspective, technology and technical changes are recognized as elements which pervasively influence economic growth, having remarkable impact on structures of national economies, shaping development patterns of countries.

The problem of inter-dependency between economic development and role of technology in fostering economic development are deeply rooted in economic theory. Theoretical background for the problem analysis is broad and mainly refers to the stream of neoclassical growth theories and macroeconomic determinants of growth. Early neoclassical models and concepts i.e. of Solow [1956], they treat technological advancement as crucial and exogenous factor of long-run economic growth. In his works, Solow assumes that technology is a public good, freely available by everyone at no cost. But based on such assumption, the long-run GDP per capita growth generated by technology adoption (in case of developing countries) shall be equal. But following works of e.g. Schumpeter or Kaldor reveal a problem of different initial condition for development, thus the growth rates differ across countries crucially. In the same vein, there appeared seminal works of Arrow [1962], who claimed the technological change to be an endogenous factor. Other significant contributions of theoretical and empirical kind were made by Uzawa [1965], Phelps [1966] or Shell [1967]. All authors mentioned above, stressed the importance of technological changes and permanent growth of technologies as determinants of significant shifts in labour force skills and abilities which should influence positively growth rates of national income. Along with the previous there emerged a remarkable literature on strictly endogenous growth models, i.e. see works of Lucas [1988], Romer [1990], Grossman and Helpman [1991], Aghion and Howitt [1992], Jones [1992, 1995], where role of technologies in fostering economic growth was highly emphasized.

In line with the literature explaining technology as a factor of economic growth, there emerged another stream in the economic theory, which combines the previous with the hypothesis of catching-up when referring to economically backward countries. The idea of implementing technology into broad development theories, in this sense, was undertaken in works of i.e. Gerschenkron [1962], Abramovitz [1986] or Maddison [1991]. Gerschenkron argues that developing countries mainly operate below the world technology (innovation) frontier and by coping (imitating) the developed technologies gain an opportunity to converge (catch-up) with developed countries in terms of economic development. The "technological congruence" standing for a lack of appropriate technology to enter development path, has also been stressed in the works of Abramovitz [1994]. Gerschenkron [1962] writes that "borrowed technology, so much and rightly stressed by Veblen [Veblen 1915], was one of the primary factors assuring a high speed of development in a backward country". Technology and innovation are to foster the catching-up process of low-income countries mainly by enabling improvements in education, diffusion of knowledge and shifts in labour productivity. The concepts cited above have also been extensively studied in empirical works of e.g. Castellacci [see Castellacci 2006, 2008, 2011] and Ben-David [see Ben-David 1997a, 1997b].

Process of technology diffusion, in the context of economic development, often yields for revealing of "network effects". "Network effects" stand for the value of potential connectivity, which – in heterogeneous societies, tends to grow exponentially. It explains fast growing number of users of given technology, which then attracts and multiplies further links. On the ground of economy, it means that the growing number of links is potentially translated into real revenues (i.g. growing GDP per capita). Following Katz and Shapiro [1985], the network effects reveal as increasing utility from usage of given good or service, when accompanied by increasing number of users of analogous goods or services. Such positive interactions make strong products even stronger and weak even weaker, which in effect can lead to simply substitution of one product by another [McGee and Sammut, 2002]. In late 1990s, Shapiro and Varian [1990] claimed that "there is a central difference between the old and new economies: the old industrial economy was driven by economies of scale; the new information economy is driven by the economics of networks".

The positive realimentation schema of revealing network effects is conditioned by achievement of a given society certain "critical mass" of technology. The critical mass theory, derived from physics [see Oliver, Marwell and Teixeira, 1985], yields to answer what are critical conditions for profitable collective actions. The critical mass in case of technologies is a worldwide phenomenon which depends on socio-demographic, cultural, institutional features of societies, extend of market competition and country`s demand for certain technologies. In some empirical works of i.e. Economides and Himmelberg`s [1995], Ivaldi [1997], Kim and Kwon [2003], Cabral [2006], we find attempts of quantification the critical mass in given societies, but in fact they mainly concentrate on tracing determinants of critical mass, while the estimates of the level of critical mass remained fuzzy.
This concept is somehow related to what was stressed in works of Baumol [1986], Perez and Soete [1988], or Verspagen [1991], that country`s ability to adopt new technologies is preconditioned by a wide array of factors. Societies assess and assimilate technological novelties relying upon "intellectual" capital [Soete and Verspagen, 1993], institutional, governmental and cultural conditions. Some empirical evidence show that the most prominent factor in country`s ability to adopt and use effectively new technologies are education and skills of labour force [Baumol, 1989]. Countries experiencing significant lacks in these probably shall never be able to use the full potential of technological change. As result they will never catch-up with richer countries, and remain as lagging behind and economically disadvantaged countries. These also suggest that process of adoption of new technologies and their contribution to growth and development is far from automatic. The possibilities of forging ahead falling behind in economic performance due to technological progress are highly influenced by factors which, in fact, might be difficult to capture.

3.2 New technologies dissemination in developing world – a promise for success?

Over the last decade (years 2000-2010) adoption of new technologies – Information and Communication Technologies (abbrev. – ICTs) in world countries has been massive and the dynamism of the process has been exceptionally high.

Led by general intuition we claim existence of causal chains between level of ICTs adoption and country`s ability to enter the pattern of long-term economic development, which in consequence would let to catch-up with the best performing economies. We assume that information and communication technologies due to their unique features like ability to spread among countries at high pace and at low cost, requiring minimal skills for usage create solid background for gains creation. On country level such gains are accounted as GDP per capita growth going along with the country's ability to diminish the economic development gap between low-, and high developed economies.

Using ICTs as a catalyzing factor for growth might play a critical role in developing and economically backward countries. The near-ubiquitous spread of information and communication technologies offers unprecedented opportunities for low-income countries to take-off on the development path, mainly by deploying ICTs tools for effective economic reforms. ICTs can play a critical role in development process, by broadening access to information and all kind of knowledge, which results in improvements of people`s empowerment, participation in socio-economic life. New technologies enable significant reduction in high information asymmetries. Reduction in such asymmetries improves access to economic activities for multitude of agents, fostering participation, *inter alias* in labour market of previously disadvantaged societal groups. Wide adoption of ICTs helps to overcome intensive constraints to growth that developing counties may experience. The significant impact of ICTs on economy in developing country might be enabled by creation of positive links between market agents, providing opportunities for more flexible work, providing new contacts, which – in effect – results in rising of economic activities with potential increases in productivity, firm efficiency, or cost reduction. In this line, ICTs bring to developing markets new business models, innovations, capital-labour substitution, improved goods and services. These account for growing competiveness of low and lower-middle-

income countries on globalized market, by offering them new markets or simple enlarging those already existing.
The full potential of new technologies can be easily unleash when deploying them as economic development accelerator in least developed countries (LDCs). The complexity of development goals that these countries have to deal with, requires adoption of adequate tools, and as stated by many – ICTs – are perceived as such. Least developed country, permanently lacking financial resources, good infrastructure, free and easily accessed to educational and healthcare systems, sound governments, remain in poverty traps, unless a breakthrough like explosion of ICTs occurs.
Now, ICTs deployment, with special focus on least developed countries, in national economies is receiving growing attention. By many ICTs are simply perceived as tools (enablers), which foster economic growth and development. Samiullah and Rao [Samiullah and Rao, 2000] argue that new technologies bring to developing countries opportunities to fight rural and urban poverty, by improving economic performance and ability to compete on global markets, they provide means for exploitation unused labour force, and increase social capital . At a time, new information and communication technologies create better ways for information flows, which open new possibilities for economic co-operation on larger scale [Kyem and LaMeire, 2006]. In addition, the nexus between new technologies and achievements of Millennium Development Goals is recognized and it is based on mutually shared objectives, which are: "efficient, scalable, affordable and pervasive delivery of goods, services and information flows between people, government and firms" [see Report prepared for the United Nations ICT Task Force in Support of the Science, Technology & Innovation Task Force of the United Nations Millennium Project, Denis Gilhooly]. ICTs are recognized as tools which can play a crucial role on the fields captured in MDGs, mainly by provision of affordable access to communication infrastructure which least developed countries lack permanently. The relevance of ICTs for focusing on MDGs achievements has been agreed at United Nations Millennium Summit in 2000. New technologies can be applied for the listed Millennium Development Goals and strategic for their accomplishments by contributing to education and creation of social opportunities, gender empowerment, improved healthcare systems [Gilhooly, 2005].

ICTs bring to developing countries wide opportunities. These are not always captured in GDP statistics, and exploration of links between technology adoption (diffusion) and economic development might not be straightforward. Impact of ICTs on economic activities is neither automatic nor homogenous across countries. It is conditioned by a bundle of factors which are often of qualitative kind. These might be religion, social structures, traditions and many others. Despite their influence is not direct nor clearly visibly, might they constitute significant constraints for effective usage of ICTs.

Also, we observe a kind of “delays” in detection of impact of new technologies on economic development. Positive effects of ICTs usage, encompassing i.e. rise of productivity, may be possible to identify with considerable time lags. These lags are accounted as “delay hypothesis” [David 1990], which reflects the time needed for adoption of new technologies along with acquiring enough skills for their effective usage. This brings to mind, that full potential of new technologies in boosting economic growth might be revealed rather in long-run perspective, while the evidence exhibited in short-run can be somehow misleading and not very conclusive.

4 Data explanation and rationale.

Main goals of the paper concentrate on providing empirical evidence on information and communication technologies diffusion dynamics and patterns, and identification of quantitative links between ICTs adoption and socio-economic development. In this line, we have selected a set of statistics which are assume to approximate the level of technological advancement of a countries – on the ground of information and communication technologies (ICTs), as well as variables explaining the socio-economic development. The time-series data we use in the study are derived from World Telecommunication/ICT Indicators Database 2012 (16th edition), World Development Indicators 2013 (access June 2013) and Human Development Report 2013. On that base we construct a cross-country panel data set which covers 46[3] low-, and lower-middle-income economies. The period of the analysis is set for 2000-2011. Full data set is presented in Statistical Appendices (see end of the paper).

3 Countries in the panel represent different all world regions (including Europe).

4.1 Information and communication technologies statistics.

The data on information and communication technologies (ICTs) are exclusively obtained from World Telecommunication/ICT Indicators Database 2012 (16^{th} on-line edition, full version). The most commonly used measures of country`s advancement on the field of adoption of ICTs are:

- Fixed-telephone Lines per 100 inhabitants (FTL_{i}[4]$_{,y}$[5]);
- Mobile-Cellular Telephone Subscriptions per 100 inhabitants ($MCS_{i,y}$);
- Internet Users[6] as share of total population ($UI_{i,y}$).

For the analytical purposes, we have transformed[7] the data on $FTL_{i,y}$ and $MCS_{i,y}$ so that they presented the share of population using given ICTs tool.
The 3 basic variables (ICTs variables) provide information on ICTs infrastructure ($FTL_{i,y}$), access ($MCS_{i,y}$), and usage ($UI_{i,y}$). They describe coherently individual country`s achievements and let tracking progress made in ICTs infrastructure, access and usage. Detailed analysis of data additionally allows identifying the level and evolution of ICTs over time, allowing for inter-country comparisons.

4.2 Economic development statistics.

The concept of socio-economic development is broad and covers multitude of aspects of human well-being. In past decades, there emerged a vast literature proposing newly developed measures of human development. The main attention in these indices is paid to non-income factors, which are linked to capabilities and functionings [i.e. Sen 1988, Dasgupta and Weale 1992, Desai 1991], accomplishment of basic needs [Streeten 1981, Sen 1987]. In this vein, we deploy 3 variables to examine the level of socio-economic development. All data

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4 Country
5 Year
6 Refers to individuals using Internet.
7 For data transformation we have used statistics on total population and total number of given ICTs tool in each country. Based on that we have estimated the share of total population using (having access) to fixed telephony and mobile telephony.

are derived from World Development Indicators 2013 (access June 2013) and Human Development Report 2013. These are:

- Gross Domestic Product per capita in Purchasing Power Parity ($GDPPPPpc_{i,y}$);
- Human Development Index ($HDI_{i,y}$);
- Female Labour Participation[8] ($FLP_{i,y}$).

The ($HDI_{i,y}$), an aggregate measure, captures 3-dimension of welfare, which are: GDP PPP *per capita*; education – approximated by mean years of schooling and expected years of schooling; and health – accounts for life expectancy at birth[9]. The value of HDI variable explains a general well-being of societies, reflecting condition and effectiveness of educational system, healthcare, allowing assessment of people`s empowerment in possibilities for wealth creation (measured in *per capita* incomes). We also add to the panel Female Labour Participation ($FLP_{i,y}$) variable. The indicator reports on women agency and access to labour market, their ability to gain financial assets which enable them to set up a business. Preliminary analysis indicates huge difference in the ($FLP_{i,y}$) value across countries, and it is clear that women`s participation in labour market cannot be explained by single factor. The constraints are often deeply rooted in culture, religion, social structures (i.e. caste system in India), poor access to education and healthcare system. It`s thought that wide adoption of information and communication technologies can bring women`s pathways for labour market empowerment, by offering access to knowledge and information, creating financing and job opportunities.

5 Estimating ICTs diffusion patterns in low and lower-middle-income countries – empirical evidence.

Empirical objectives of the first part of the analysis are twofold. Firstly, we aim to concentrate on detecting changes in distribution of the 3 ICTs variables in the period of 2000-2011 in 46 countries. Secondly, we wish to contribute by verifying the hypothesis on existence of S-

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8 Labour Participation Rate – stands for the share of female population aged 15+ which are active participants of labour market (WDI 2013)

9 World Development Indicators 2013.

shaped ICTs diffusion patterns, along with estimates of the simple logistic models parameters (for each country separately).

5.1 Information and communication technologies in developing countries – descriptive statistics of the data.

To start up our analysis, we make a necessary clarification of the descriptive statistic of the data used in the study. For better understanding of the process of ICTs diffusion dynamics, this seems crucial as it provides general ideas on average levels of ICTs adoption in low and lower-middle-income countries.

Our descriptive analysis consists of two essential parts. Firstly we present a cross-country basic statistics on $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$ deployment in 46 selected economies. We report on averages, minimum and maximum values of variables in the sample, we confront the lower quintile with upper quintile, as well as we identify basic inequalities in distribution of ICTs. By these we mean to underline general features of the distribution of ICTs in selected countries, as well as to capture its changes in the analyzed period 2000-2011. In the second part of the following section we plot non-parametric estimates of densities functions[10] for each variable separately, to identify general trends in graphical distributions (involving smoothed structure) of selected data. Such visualization facilitates interpretation of changes in distribution of univariate data, also adding to full understanding of the data structure.

Table 1, (below) lists the cross-country descriptive statistics of the data, along with Gini coefficients, Atkinson and Entropy indexes. We estimate the values for each variable: $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$, during the period 2000-2011.

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[10] Kernel Epanechnikov.

Table 1. Descriptive statistics for $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$. 46 countries. 2000-2011.

Variable	Average (%)	Min. Value (%)	Max. Value (%)	Lower quintile	Upper quintile	Gini coeff.	Atkinson index	Entropy index
$FTL_{i,2000}$	4,3	0,18	21,3	0,76	5,29	0,57	0,27	0,66
$FTL_{i,2011}$	7,3	0,34	33,28	1,33	10,53	0,56	0,26	0,63
$MCS_{i,2000}$	2,34	0,018	15,36	0,21	2,85	0,66	0,38	1,07
$MCS_{i,2011}$	77,08	21,31	143,3	55,7	99,4	0,21	0,037	0,069
$IU_{i,2000}$	0,69	0,036	5,96	0,15	1,04	0,56	0,26	0,93
$IU_{i,2011}$	17,51	1,3	51,0	7,0	28,0	0,39	0,13	0,25

Source: author`s estimates using data from World Telecommunication/ICT Indicators Database 2012 (16th on-line edition, full version).

The most crucial observation which can be derived from the Table 1, is that in the analyzed period (2000-2011), the dynamic of the process of ICTs adoption on developing countries was astonishingly high. Changes in mobile telephony and internet usage are deep and massive, and explain a general worldwide tendency on broad adoption on "new" forms of ICTs in economically backward countries. Focusing exclusively on changes in $MCS_{i,y}$ variable, we clearly see that in 2000 the average level of adoption of mobile cellular telephony was at only $MCS_{Aaverallcountries,2000}$ = 2,34%; while the analogous value in 2011 resulted as $MCS_{Averallcountries,2011}$ = 77,08%. To highlight the minimum and maximum values in both years, we detect that the most 2 backward countries in 2000 and 2011, in terms of $MCS_{i,y}$ adoption were respectively: Niger – $MCS_{Niger,2000}$ = 0,018%, and Nigeria – $MCS_{Nigeria,2000}$ = 0,02%; Djibouti - $MCS_{Djibouti,2011}$ = 21,32%, and Malawi – $MCS_{Malawi,2011}$ = 25,69%. The evidence also shows that the best performing country in 2000 was Paraguay – $MCS_{Paraguay,2000}$ = 15,36%, while in 2011, it was Viet Nam with the value $MCS_{VietNam,2011}$ = 143,3%. So, in the period of 2000-2011 the minimum value grew at $MCS_{Min2011-Min2000}$ = 15,34% of share of population using mobile telephony; while the maximum values grew at $MCS_{Max2011-Max2000}$ = 117,61% of the same unit. Analyzing changes in lower and upper quintiles (when we divide population into 5 equal-sized groups) we conclude that in 2000 the average adoption of $MCS_{i,y}$ in the group of 20% poorest of countries was at 0,22% (of total population), while in

2011 – 55,7%. The analogous values but referring to upper quintile (accounts for the group of 20% best performing countries) in 2000 and 2011 were respectively (2,85%) and (99,4%).
Quite similar, however not so explosive, changes are noted for Internet use by individuals in developing countries. The average use of Internet increased from $IU_{Averallcountries, 2000}$ = 0,69% to $IU_{Averallcountries}$ = 17,51%. It stands for fact, that in 2000 the average usage of Internet by countries` societies was close to 0%, while in 2011 almost 20% (on average) of society members were using Internet. Countries which underwent the most impressive increases in Internet usage were: Nigeria [$IU_{Nigeria,2000}$ = 0,06% $\rightarrow$ $IU_{Nigeria,2011}$ = 28,48%], Albania [$IU_{Albania,2000}$ = 0,11% $\rightarrow$ $IU_{Nigeria,2011}$ = 49%], Morocco [$IU_{Morocco,2000}$ = 0,69% $\rightarrow$ $IU_{Morocco,2011}$ = 51%], Moldova [$IU_{Moldova,2000}$ = 1,28% $\rightarrow$ $IU_{Moldova,2011}$ = 38%], and Georgia [$IU_{Georgia,2000}$ = 0,48% $\rightarrow$ $IU_{Georgia,2011}$ = 36,56%]. It proofs an increasingly important role of new mean of communication even in the poorest countries of the world. Such changes are of particular importance, and bring to these countries the "missing" link enabling creation of positive impact on economy.
As expected, changes in adoption and usage of the "old" form of mass communication – fixed telephone lines ($FTL_{y,i}$) are relatively slight in the period of 2000-2011, when comparing to the $MCS_{i,y}$ and $IU_{i,y}$ previously analyzed. Such weak increases in adoption of fixed telephony are probably caused by simply substitution of "old" forms by "new" forms of communication (in the case mobile telephony). This also might be explained by the fact that mobile telephony is cheap in usage, is easily acquirable and requires minimum hard infrastructure. Easiness and low costs of adoption of mobile telephony even in low and lower-middle-income countries, supports the hypothesis of adequacy of ICTs – as possible tools for development – in economically backward countries.
Additionally, we report on disparities in ICTs distribution by applying classical inequality measures like Gini coefficient, Atkinson and Entropy indices. Values of given indices include crucial information on (equal/unequal) distribution of ICTs tools among society members in selected countries, showing on relative deprivation from access to given means of communication like fixed telephony, mobile telephony and Internet. While the Gini coefficient equals 0 it corresponds with perfectly equal distribution (stands for no deprivation) with respect to given resource (in our case ICTs tools). Using Gini coefficient as a

representative inequality measure in such heterogeneous sample of countries, is rather comfortable as it “hides” the statistical impact of outliers which are observed in the field. As control inequality measures, we additionally apply Atkinson and Entropy indices. Again the cited indices define maximum inequality (aversion to equality) with 1, and maximum equality with 0. The entropy index gives the idea on randomness of distribution, explaining the magnitude of relative entropic distance from total egalitarianism when everyone in the society has the same (equal) access to resources (again ICTs tools in the case).

The Table 1, also displays final estimates of Gini, Atkinson and Entropy measures. It shows that intensive growth in $MCS_{i,y}$ and $IU_{i,y}$ adoption goes along with significant decreases in inequalities of given variables. In 2000 the $GINI_{MCS}$ was 0,66, and has fallen till $GINI_{MCS}$ = 0,21 in 2011, while for Internet usage the values were respectively: $GINI_{IU}$ = 0,56 in 2000 and $GINI_{IU}$ = 0,39 in 2011. The same tendency is reported for the next two inequality measures, Atkinson and Entropy indices (for detailed values see Table 1 above). This stands behind far more equal distribution of ICTs among society members in all analyzed countries. It is worth noting that more dynamic spread of mobile telephony than Internet in developing countries, has contributed more significantly to inequalities reduction for $MCS_{i,y}$ variable than $IU_{i.y}$. It shows that ICTs spread in developing countries is highly advantageous process reducing inequalities in access to ICTs infrastructure. The $FTL_{i,y}$ again is an exception as hardly no changes in distribution of this kind of ICTs tool is reported.

However, descriptive statistics do not contain too much information on ICTs variables ($FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$) distribution across countries, we provide a complimentary analysis for the previously obtained results. We propose separate densities plots to illustrate significant variations which occurred in ICTs distribution the period 2000-2011 both in low and lower-middle-income countries.

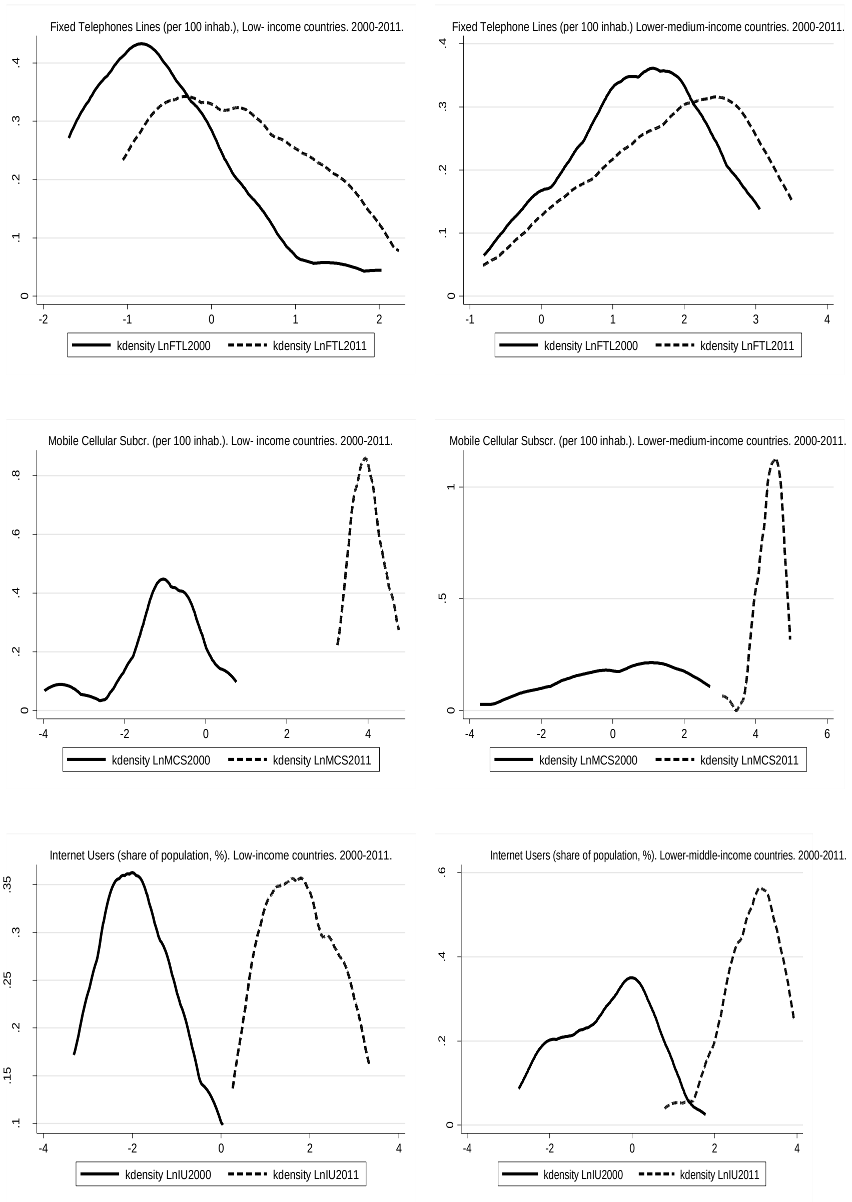


Fig. 2. Density representations for $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$ by income groups. Years 2000 and 2011.

On each chart, the solid line stands for the distribution approximation of $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$ in 2000, while the dash line – in year 2011. As expected, in case of fixed telephony densities plots, changes are not significant and densities lines hardly change in shape and location. In case of low-income countries changes in $FTL_{i,y}$ distribution are slightly stronger than in case of lower-middle-income ones, but still remain weak. When turning to the analysis of density plots for $MCS_{i,y}$ and $IU_{i,y}$ the changes both in shape and location are striking. In case of $MCS_{i,y}$, for both country groups, density lines have "moved" to the right, resulting to be unimodal, highly peaked and tall in 2011. This again let us to confirm the observation on diminishing inequalities in access to this kind of ICTs by society members in analyzed countries. Analogous results are revealed in case of $IU_{i,y}$ data smoothing using Kernels. Rather unimodal lines, in both country income sets, again similar in shape, but more right-located in 2011 than in 2000. The densities estimates suggest that changes in ICTs distribution were relatively more pervasive in the group of lower-middle-income countries, which inter alias can be conclude from significant reshapes of distributional lines.

5.2 ICTs diffusion trajectories in 46 developing economies.

Expansion of new technologies in developing countries shall additionaly be explained through the lens of the dynamism of in-time diffusion within countries. When discussing developing countries, surely the diffusion of new information and communication technologies is actually a process of direct imitation of ICTs from technologically-advanced countries. The imitation often brings to mind a kind of "bandwagon effect" [Soete and Verspagen, 1993], which is quite typical for low-income economies.

The study of ICTs diffusion enables us to discover the longitude of the process, as for many countries included in the sample we possess data for the first years in which ICTs were implemented. Therefore, the assumed estimates of "full" S-shaped curve are highly facilitated. As was already clarified the previous sections, in macroscopic perspective, the S-shaped diffusion trajectories are generated mostly by the heterogeneity of large populations which adopt innovation [Shimogawa *et al.* 2012]. As result patterns of adoption in different countries are expected to be far from homogenous.

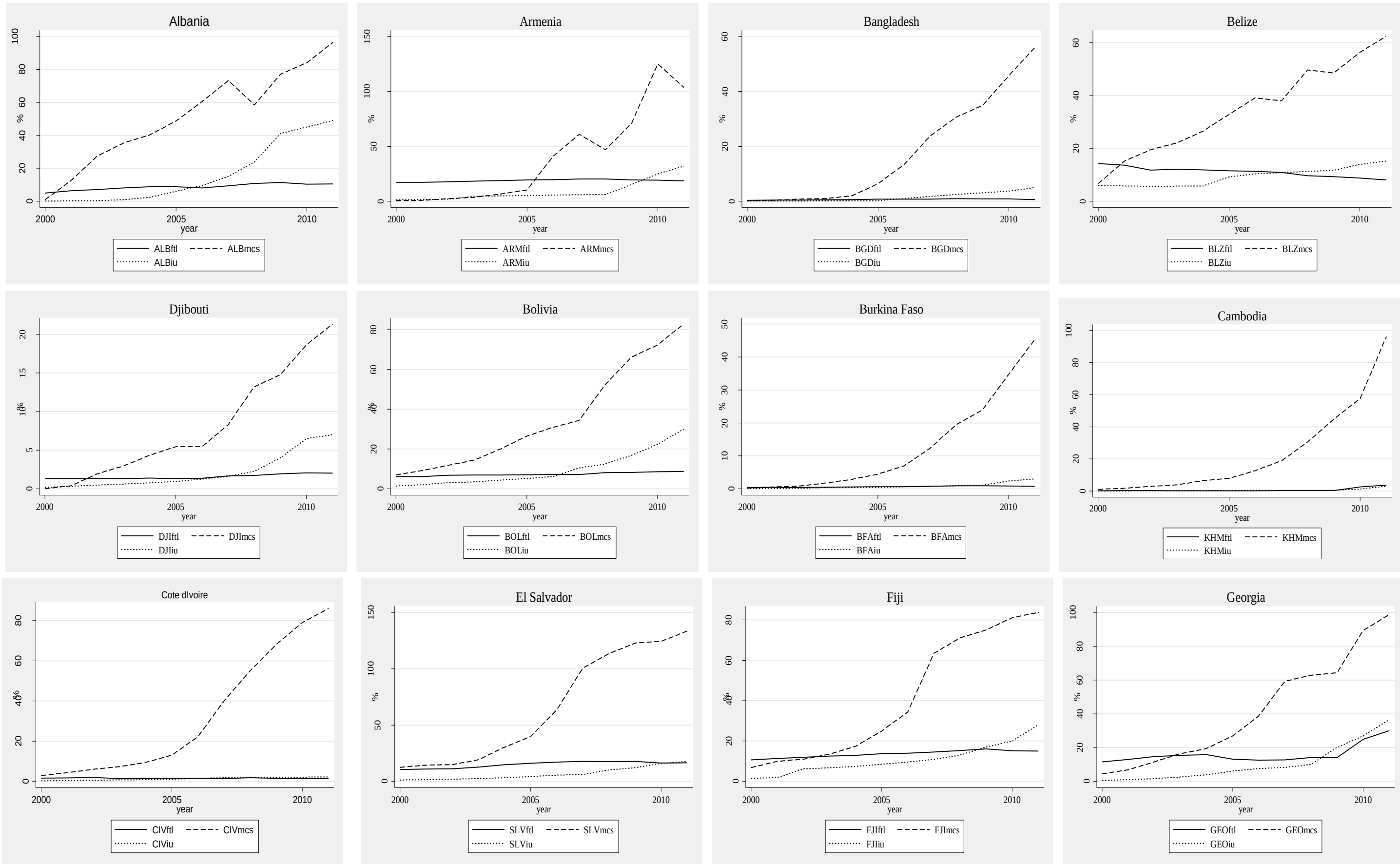
For detailed estimates of the S-shaped curve parameters, we run 46[11] logistic models, of high predictive capacity, assuming time (t) to be explanatory variable.
The individual country model specification is following:

$$\begin{cases} P(t)_{(1,2000-2011)} = \frac{\kappa_{(1,2000-2011)}}{1+\exp(-\alpha_{(1,2000-2011)}(t-\beta_{(1,2000-2011)})} \\ P(t)_{(2,2000-2011)} = \frac{\kappa_{(2,2000-2011)}}{1+\exp(-\alpha_{(2,2000-2011)}(t-\beta_{(2,2000-2011)})} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ P(t)_{(46,2000-2011)} = \frac{\kappa_{(46,2000-2011)}}{1+\exp(-\alpha_{(46,2000-2011)}(t-\beta_{(46,2000-2011)})} \end{cases} \quad (5)$$

Following the formalized logistic models of technology diffusion, we estimate the parameters of each model: α (specific duration), β (midpoint) and κ (limit of growth, maximum/potential level of saturation). Along with the logistic models estimates we plot ICTs diffusion lines for each of the 46 studied countries separately. A set of plots (see Fig. 3 below) presents diffusion trajectories for $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$ in each country in the period 2000-2011. Graphical approximation of ICTs diffusion patterns, intuitive to interpret, allows for general assessment and inter-country comparisons of process dynamics in time. Such approach also let us to discover existing regularities and tendencies in technology diffusion process in developing countries.
The first thing to notice is that in many case the fit of the data to theoretical S-shaped curve is quite good. Moreover, lots of low and lower-middle-income countries appreciate very clear S-shaped patterns of ICTs diffusion, especially with respect to mobile telephony ($MCS_{i,y}$). In many cases the full S-shaped trajectory is revealed. This occurs i.e.

[11] We estimate the model for each country separately.

in case of Ukraine, Fiji, El Salvador, Sri Lanka, Paraguay, Pakistan, Côte d`Ivoire, or Zimbabw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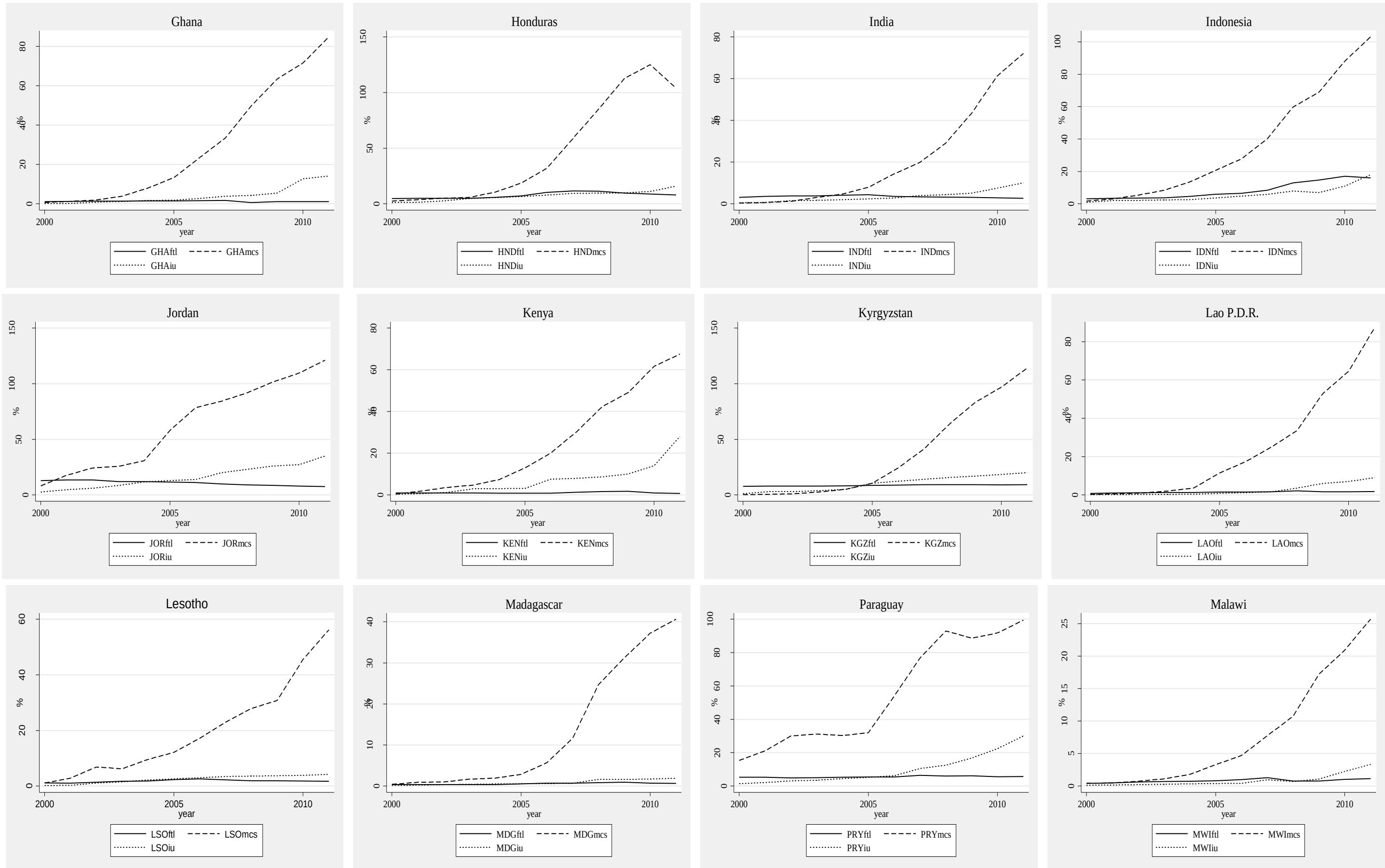

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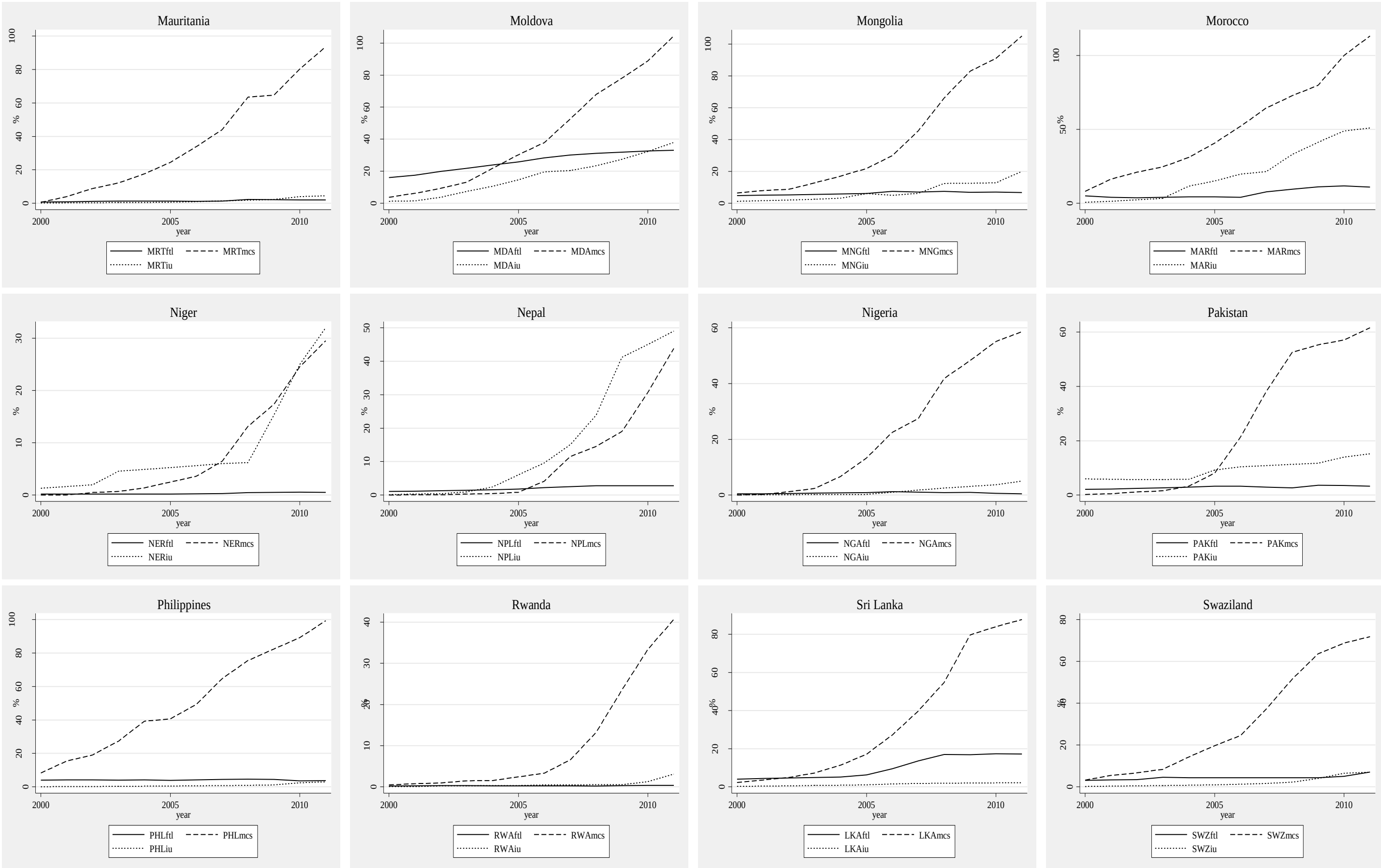
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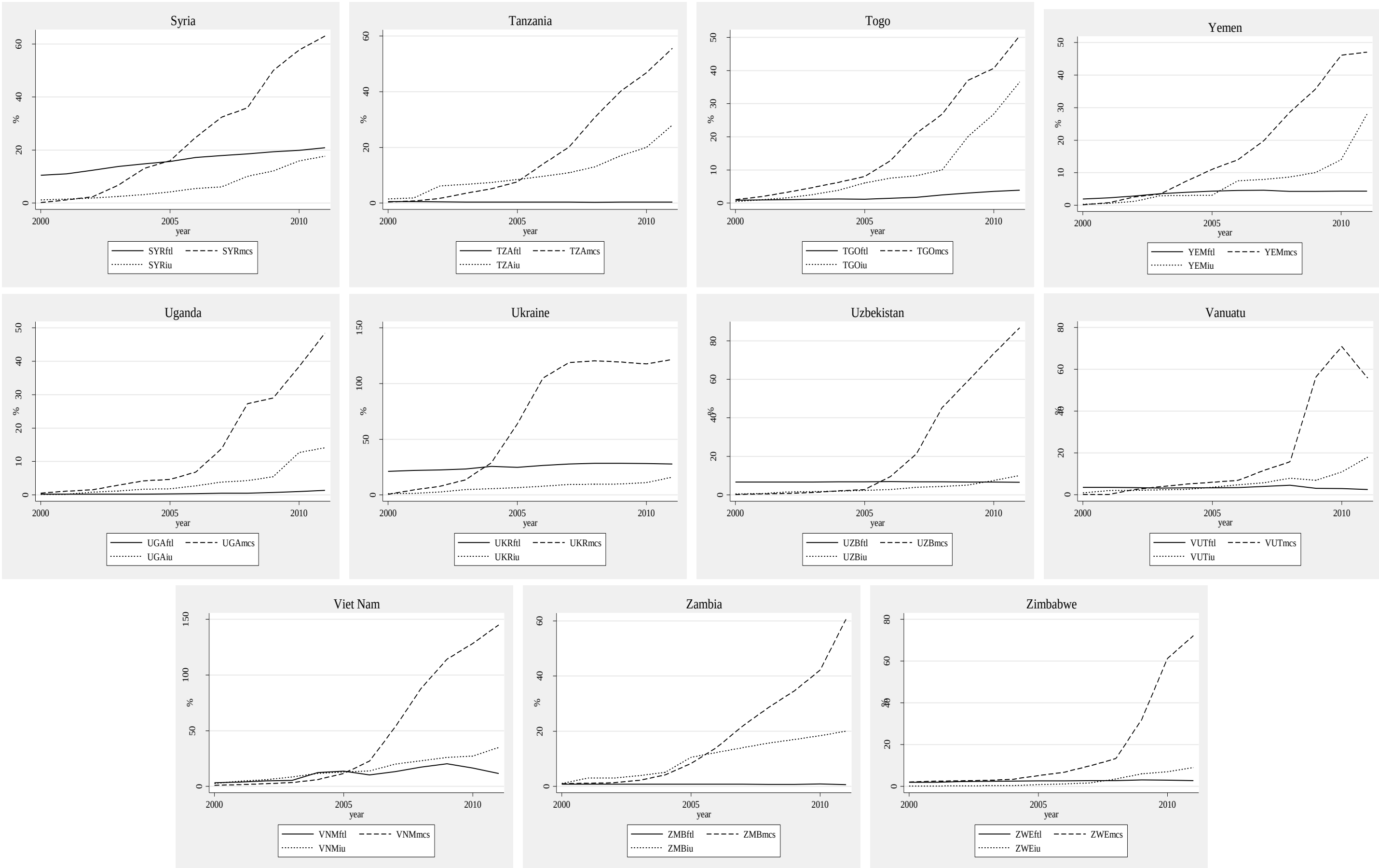

Fig. 3. ICTs diffusion trajectories in 46 low and Lower-middle-income countries. Country`s individual patterns. Period 2000-2011. Source: author`s own elaboration**.**

It is highly suggestive that in many countries the S-shaped curve for $MCS_{i,y}$ is generated. The diffusion of mobile telephony was relatively slow in the initial years, then it sped up in the middle years and slowed down in the final phase (in 2011 and few years before). We need to remember that the analyzed period in almost each country in the sample, in 2000 the level of average adoption of mobile telephony was close to zero, or at very low level (for details see statistics in Appendix 1). After 11-year period of extraordinary dynamic growth of this mean of communication, in many countries the average level of adoption of $MCS_{i,y}$ (as share of total population using mobile telephony) reached astonishingly high level of close to 100% or even more. The number of countries that could be cited as examples is abundant. The share of total population using mobile phones exceeding 100%, occurred i.e. in Armenia ($MCS_{Armernia,2011}$=103%), Honduras ($MCS_{Honduras,2011}$=103%), Kyrgyzstan ($MCS_{Kyrgystan,2011}$=113%), Viet Nam ($MCS_{VietNam,2011}$=144%). In each of these countries, in 2000, the share of population using MCS range between $<MCS_{i,2000}=0,18\%>$ and $<MCS_{i,2000}=2,5\%>$. Is suggest that within the 11-year period each of these countries have passed the full diffusion curve, and in 2011 approached to the upper asymptote (limit of growth), which stands for almost full saturation with $MCS_{i,y}$ in given societies. Examining the average annual growth rates of $MCS_{i,y}$ diffusion, we discover that it results to be at about 38% annually[12]. In the sample we can find countries which achieved the average annual growth rate of 67% (Niger), 63% (Nepal), 59% (Kyrgyzstan). The lowest rate is noted for Paraguay, and it was 17% in 2011.

In case of variable explaining Internet users as share of total population ($IU_{i,y}$), the results suggests that most of countries in the sample they are rather located in the first parts of S-shaped pattern. In none of the case, the full S-shaped curve is generated. This implies that diffusion of Internet in low and lower-middle-income countries, in the period 2000-2011, was rather in initial phase. Analyzing graphical approximations of $IU_{i,y}$ diffusion process, we would rather conclude that most of developing countries enter the exponential growth phase in S-shaped trajectory. These countries are passing the “take-off” phase, than already enjoy high saturation with Internet. More detailed analysis of countries` specific statistic on $IU_{i,y}$ both in 2000 and 2011, provides the

[12] Author`s estimates.

picture on average level of adoption of Internet in analyzed countries. In 2011 the best performing countries were Morocco – $IU_{Morocco,2011}$=51%, Albania – $UI_{Albania,2011}$=49%, Moldova – $IU_{Moldova,2011}$=38%, and Georgia – $IU_{Georgia,2011}$=36%. These results, although being impressive, are significantly lower than in case of mobile phones adoption rates. This is probably due to the fact, that adoption and usage of Internet – however bringing more possibilities than just mobile telephony – requires a greater "mass" of already installed hard infrastructure. If so, the implementation of Internet to developing countries is much more costly, than provision of the society members with mobile phones. As low and lower-middle-income countries experience substantial lacks in financial resources, this might constitute a significant hindrance.

In the rest of the section [using formula (5)] we estimate the logistic models parameters for each country separately. Basing on the graphical approximations of diffusion patterns, we conclude that the full S-shaped curve estimates are only reasonable for the variable $MCS_{i,y}$. While for $IU_{i,y}$ and $FTL_{i,y}$ the S-shaped curves were not revealed.

All generated results are presented in Table 2 (see below). Applying the *ceteris paribus*, we conclude that parameter κ, explains the potential limits of growth of variable in each country. Surely its value is generated using available statistics and basing on silent assumption that trend of diffusion shall be maintained. For low-income countries the estimated limits of growth of $MCS_{i,y}$ are definitely lower than in case of lower—middle income countries. Unreasonably high κ results to be in case of Cambodia ($\kappa_{Cambodia}$=345), but such estimates are probably due to specific jump in $MCS_{Cambodia,y}$ value in years 2000-2011 (it was at 60% of annual growth).

The parameter α controls for the specific duration, approximating time (years) needed for a country to pass from the saturation (explaining share of population "contaminated" by given technology) level 10% to 90%. As we see from Table 2, the average characteristic duration in low-income countries was $\alpha_{averageLow\text{-}incomeCountries}$=8,5 years. It suggests that an "average" low-income country needs only 8,5 years to achieve the level of saturation at 90% with respect to mobile telephony, still keeping the strict assumption on maintenance of diffusion rates that were reported for the period 2000-2011. The β parameter for diffusion curves, identifies the midpoint, which stands for a specific for years when given country passes from the exponential growth phase to stabilization phase. The average value of β in low-income counties is reported as $\beta_{AverageLow\text{-}incomeCountries}$=*(year)*2009. Is allows to summarize, on average, each of 15 low-income countries in the sample has passed the midpoint in 2009. After the year 2009, diffusion slows approaching to upper asymptote κ.

The analogous estimates are reported for 31 lower-middle-income countries (for detailed results again see Table 2). As already noticed, the κ in this income group results to be generally higher, achieving the average level of $\kappa_{AverageLowerMiddleIncomeCountries}$=94,6%. Considering the specific duration (in years) and midpoints for this income country groups, the values determined by the models are (on average): $\alpha_{AverageLowerMiddleIncome}$=8 (years), and $\beta_{AverageLowerMiddleIncome}$=*(year)*2007. It shows that – on average – lower-middle-income countries pass the inflection point on the S-shaped curve 2 years earlier than low-income economies. This is determined by relatively higher dynamics of $MCS_{i,y}$ diffusion in "richer" countries.

The latest analysis reflects extremely high dynamism of the process of implementation of new mean of communication across developing countries, and confirms general conclusion outlined in the previous section proofing again pervasive changes in ICTs adoption.

In here we shall however underline, that these estimates base on rigid assumptions. We arbitrary foresee that all analyzed countries shall follow the same diffusion pattern and maintain the previously achieved diffusion rates. However the heterogeneity of factors conditioning the future diffusion paths is huge. Technology diffusion is up to institutional regulations, market competition, societies` ability to assimilate innovations, which depends on education level but also on religious or cultural customs. As we know, the factors listed above play crucial role, especially in developing countries.

Taking into account the fast changing, and in many case highly unstable, external environment, such optimistic scenario is not very probable, however indicates some general trends of ICTs diffusion in low and lower-middle-income countries.

Table 2. MCS variable logistic models estimates. 46 countries. Years 2000-2011.

Country	**κ [%] [upper asymptote]**	**α [years] [specific duration]**	**β [year] [midpoint]**
Low-income countries			
Bangladesh	65,6	7,5	2008
Burkina Faso	84,2	9	2011
Cambodia	*345*	11,3	2014
Kenya	79,4	7,9	2004
Kyrgyzstan	123,5	6	2008
Madagascar	42	4,5	2008
Malawi	36	7,9	2008
Mauritania	118,7	10,9	2008
Nepal	101,1	8,2	2012
Niger	37,8	6,5	2009
Rwanda	49,9	5,3	2009
Tanzania	66,9	7,6	2008
Togo	61,5	8,3	2009
Uganda	62,9	7,7	2009
Zimbabwe	51,9	12,1	2015
Average for all low-income countries	84,6	8,5	2009
Lower-middle-income countries			
Country	**κ [%] [upper asymptote]**	**α [years] [specific duration]**	**β [year] [midpoint]**
Albania	94,6	10,9	2005
Armenia	134,9	7,5	2008
Belize	64,5	12,6	2006
Bolivia	100,9	6,9	2009
Cote d'Ivoire	89	5,9	2008
Djibouti	32,8	11	2009
El Salvador	119,3	4,6	2006
Fiji	76,9	4,9	2006
Georgia	117,1	10	2008
Ghana	96,5	7,3	2008
Honduras	117,0	4,2	2007
India	108,5	8,0	2010
Indonesia	132,1	8,7	2009
Lao P.D.R.	148,0	8,9	2010
Lesotho	77,3	12,5	2010
Moldova	118,1	9,1	2008
Mongolia	119,9	7,0	2008
Morocco	145,0	12,1	2009
Nigeria	62,8	6,6	2007
Pakistan	59,7	3,7	2006
Paraguay	86,0	6,1	2006
Philippines	102,7	10,2	2007
Sri Lanka	95,7	6,3	2007
Swaziland	77,0	7,0	2007
Syria	77,1	9,3	2008
Ukraine	121,4	3,2	2005
Uzbekistan	91,2	4,8	2008
Vanuatu	59,1	12,5	2014
Vietnam	146,2	4,6	2008
Yemen	59,9	8,5	2008
Zambia	114,1	10,6	2011
Average for all lower-middle-income countries	94,6	8,0	2007

Note: All estimates are generated *by LogLet Lab2* software Source: author`s estimates.

6 Tracing effects of ICTs adoption on economic development – a trial of quantification.

In previous section we have identified diffusion patterns of ICTs in 46 low and lower-middle-income countries. We have found that different ICTs tools shape different models of technology adoption, *albeit* in most of cases the dynamics of the process was astonishingly massive. In the same vein the final part of the paper summarizes the available evidence by extended trial of detection some regularities on impact of new technologies adoption on economic development across selected countries. We wish to quantify the general ideas clarified in the section 2, by seeking for empirical evidence whether and to what extent digitalization process explains progress in socio-economic development and identifying existing systematic patterns of relationship between selected ICTs variables and proxies of economic development.
Running our analysis on aggregated macroeconomic data on ICTs ($FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$) and economic development ($GDPPPPpc_{i,y}$, $HDI_{i,y}$ and $FLP_{i,y}$),we deploy an econometric approach to capture the impact of ICTs diffusion on general welfare in developing countries. We use a bivariate analysis, applying log transformed variables of the original data[13]. In details, we aim to model the influence of two selected ICTs *($MCS_{i,y}$ and $IU_{i,y}$)* deployment on economic development. As the $FTL_{i,y}$ variable shows hardly no changes in analyzed period (see distributional plots in previous section), we exclude the variable from further analyzes. Anyhow, such low variability across counties and in time would probably result in no significant results in assessing its impact on economic growth and/or development.
To quantify the impact of ICTs adoption on economic development we estimate a set of models, with three different dependent variables specified, which are: $GDPPPPpc_{i,y}$, $HDI_{i,y}$ and $FLP_{i,y}$, which we assume to be proxies of economic development of countries. As stated previously, the selected independent variables are $MCS_{i,y}$ and $IU_{i,y}$.

---

[13] All data on GDPPPPpc, HDI and FLP are available in Appendix 2.

Summarizing the above, our empirical settings are based on the following GLM equations[14]:

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,y} + \delta_2 \ln IU_{i,y} + \varepsilon_{i,y} \qquad (6),$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,y} + \delta_2 \ln IU_{i,y} + \varepsilon_{i,y} \qquad (7),$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,y} + \delta_2 \ln IU_{i,y} + \varepsilon_{i,y} \qquad (8),$$

where $GDPPPPpc_{i,2011}$ denotes gross domestic product (in PPP) *per capita* in *i*-country in 2011, $HDI_{i,2011}$ –Human Development Index in *i*-country in 2011, and $FLP_{i,2011}$ – Female Labour Participation in *i*-country in 2011. The dependent variables reporting on the level of adoption and usage of basic ICTs tools are expressed as: $MCS_{i,y}$ - shows on the share of population using Mobile-Cellular Telephones in *i*-country in *y*-year; and the $IU_{i,y}$ – shows the share of population[15] which are treated as Internet Users in *i*-country in *y*-year.

Generally we hypothesize on detecting positive impact of ICTs deployment on economic development and growth. However, it should be underlined that direct results from investments in ICTs infrastructure, its adoption and usage might be visible with significant time lags. Relaying on the "delay hypothesis" (David 1990), we assume that the "technological revolution" can take please without causing any straightforward changes in total factor productivity.

Following this, we aim to reformulate the equations *(6)*, *(7)* and *(8)* by adding the time lag variables. We identify the impact of ICTs on $GDPPPPpc_{i,2011}$, $HDI_{i,2011}$ and $FLP_{i,2011}$ values by imposing lagged explanatory variables in periods *(y-1)*, *(y-2)*, *(y-5)* and *(y-11)*. Assuming that *y* stands for year 2011, the final equations are formalized as:

for economic growth

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-1)} + \delta_2 \ln IU_{i,(y-1)} + \varepsilon_{i,(y-1)} \qquad (9)$$

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-2)} + \delta_2 \ln IU_{i,(y-2)} + \varepsilon_{i,(y-2)} \qquad (10)$$

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-5)} + \delta_2 \ln IU_{i,(y-5)} + \varepsilon_{i,(y-5)} \qquad (11)$$

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[14] We have chosen Generalized Linear Model (GLM) techniques.

[15] Refers to individuals.

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-11)} + \delta_2 \ln IU_{i,(y-11)} + \varepsilon_{i,(y-11)} \quad (12)$$

for Human Development Index

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-1)} + \delta_2 \ln IU_{i,(y-1)} + \varepsilon_{i,(y-1)} \quad (13)$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-2)} + \delta_2 \ln IU_{i,(y-2)} + \varepsilon_{i,(y-2)} \quad (14)$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-5)} + \delta_2 \ln IU_{i,(y-5)} + \varepsilon_{i,(y-5)} \quad (15)$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-11)} + \delta_2 \ln IU_{i,(y-11)} + \varepsilon_{i,(y-11)} \quad (16)$$

for Female Labour Participation

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-1)} + \delta_2 \ln IU_{i,(y-1)} + \varepsilon_{i,(y-1)} \quad (17)$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-2)} + \delta_2 \ln IU_{i,(y-2)} + \varepsilon_{i,(y-2)} \quad (18)$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-5)} + \delta_2 \ln IU_{i,(y-5)} + \varepsilon_{i,(y-5)} \quad (19)$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-11)} + \delta_2 \ln IU_{i,(y-11)} + \varepsilon_{i,(y-11)} \quad (20)$$

Table 3 (below) summarizes estimations results of each of 12 bivariate regression. The δ_1 and δ_2 parameters report on positive or negative impact of ICTs adoption on economic growth (estimates of equations 9-12), human development (estimates of equations13-16) and women participation in labour market (estimates of equations 17-20).

Firstly we observe, that the relationship between ICTs adoption – specified for both variables $MCS_{i,y}$ and $IU_{i,y}$ – and Female Labour Participating, is neither strongly positive nor statistically significant. In each case – regardless time lags – the δ_2 is negative. This would suggest that broader usage of Internet by individuals impacts negatively women`s empowerment on labour market. These results odd with elementary logic. Having in mind that ICTs enable people with better access to education, resources (including finance), easies jobs creation and many others, we would expect the influence to be high and positive. However it is not. The possible explanation for this is that, the impact of new technologies adoption requires more time to cause significant changes in labour market structures, when female and male labour participation is described.

Table 3. GLM estimates of ICTs impact on GDP PPP *per capita*, Human Development Index and Female Labour Participation. 46 countries. Period 2000-2011.

	$GDPPPPpc_{allcountries,2011}$	$HDI_{allcountries,2011}$	$FLP_{allcountries,2011}$
$MCS_{i,(y-1)}$	**δ_1 = 0,672**	**δ_1 = 0,241**	δ_1 = 0,130
$IU_{i,(y-1)}$	**δ_2 = 0,270**	**δ_2 = 0,09**	δ_2 = [-0,13]
$MCS_{i,(y-2)}$	**δ_1 = 0,729**	**δ_1 = 0,241**	δ_1 = 0,064
$IU_{i,(y-2)}$	**δ_2 = 0,184**	**δ_2 = 0,071**	δ_2 = [-0,11]
$MCS_{i,(y-5)}$	**δ_1 = 0,588**	**δ_1 = 0,151**	δ_1 = [-0,07]
$IU_{i,(y-5)}$	δ_2 = 0,077	**δ_2 = 0,063**	δ_2 = [-0,03]
$MCS_{i,(y-11)}$	δ_1 = 0,088	δ_1 = 0,031	δ_1 = [0,59]
$IU_{i,(y-11)}$	**δ_2 = 0,26**	**δ_2 = 0,097**	δ_2 = [-0,11]

Note: all estimates for 5% significance level. In bolds – parameters statistically significant. Constant reported – not included. Source: author`s own estimates.

Women`s access to labour market, in many cases, can be limited due to region and cultural barriers, habits and customs in different countries, legal regulations and girls` access to basic education. These constraints of "formal" nature are hardly possible to overcome, by simple adoption of new technologies. We also need to remember about rather limited to 11-year historical perspective. Evidently, short-run analysis may not reveal structural changes in countries` internal markets.

Opposable, to the previously discussed result, the picture that follows from the (9)-(16) regression estimates are remarkable. They seem to confirm the hypothesis on existing technology-driven growth and development. The positive links are revealed even in very short-run perspective (1 and 2-year lags). The values of δ_1 for 1-, and 2-year lags, suggest that the impact of mobile telephony on gross domestic product (in PPP *per capita*) is strong, positive and statistically significant. The highest impact - explained by highest values of δ_1, is reported for $MCS_{i,(y-2)}$, and states for [δ_1=0,729]. For 1-year lag the [δ_1=0,672] ,and 5-year lag [δ_1=0,588]. The statistically insignificant relationship is reported for the 11-year lag. Considering the impact of Internet use for growth, the estimates report similar relationship, however weaker in all cases. The identified relatively stronger impact of $MCS_{i,y}$ than $IU_{i,y}$ on growth, might be argued by the fact that, on average, share of total population using Internet is much lower in many countries than respective values for mobile telephony. Probably the saturation with Internet is still too weak to reveal positive network effects of new technology adoption.

Again, estimates for $HDI_{i,2011}$ as dependent variable contribute by analogues results. The potential impact on level of human development of $MCS_{i,y}$ for 1-, 2-, and 5-year lags is positive and significant, with estimated parameters δ_1=0,241 (1-year lag), δ_1=0,241 (2-year lag) and δ_1=0,151 (5-year lag). In case of estimates for 11-year lags, the δ_1 and δ_2 show on similar tendencies. Despite the fact, that the estimated effects of $MCS_{i,y}$ and $IU_{i,y}$ adoption on human development are as hypothesized, the impact in weaker than for pure gross domestic product. Human Development Index is a complex, aggregate measure, which captures 3 dimensions: income, education (expressed as mean years of schooling, and expected years in schooling) and health (expressed as life expectancy at birth). As in case of Female Labour Participation the sensitivity for changes of the variables in education and health is low in such short time perspective. In other words, the social components of $HDI_{i,y}$ variable are not supposed to increase/decrease significantly in 11-years period. The prolongation of life expectancy or increases in expected years of schooling, require deep and costly institutional and structural changes, financial resources, and active social and economic policy. These are usually hardly acquirable in least developed countries in short-run perspective.

To provide more clarity to our estimates, and reveal existing relationships between ICTs and economic development, we draw following 24 scatterplots. Figures 7 and 8, plot statistical relationships between $MCS_{i,y}$ and $IU_{i,y}$ adoption and Gross Domestic Product ($GDPPPPpc_{i,2011}$) *per capita* in 2011 (Fig.7) and $IU_{i,y}$ and the same dependent variable (Fig.8). Following plots in Figures 9-12, extrapolate relationships between the same ICTs variables, but as dependent variables are Human Development Index in 2011 (Fig. 9 and 10), and Female Labour Participation in 2011 (Fig. 11 and 12).

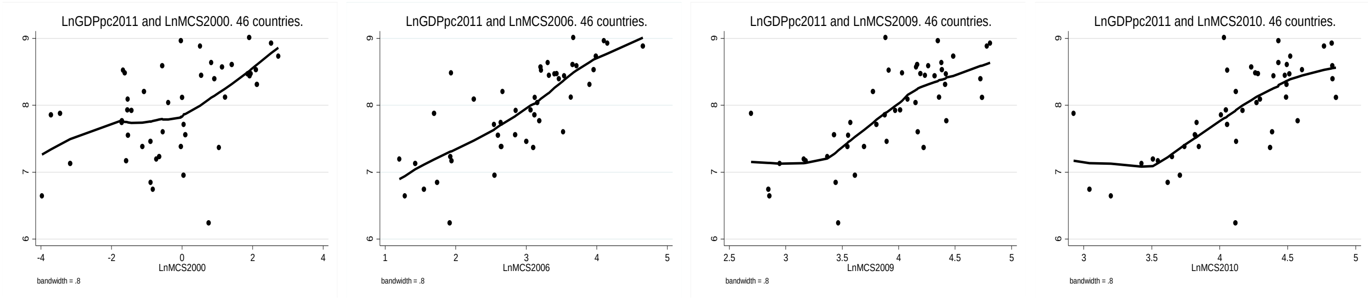

Fig. 4. Relationships between MCS adoption in 2000, 2006, 2009, 2010 and GDP PPP per capita in 2011. Non-parametric plots. Specification for 46 countries.

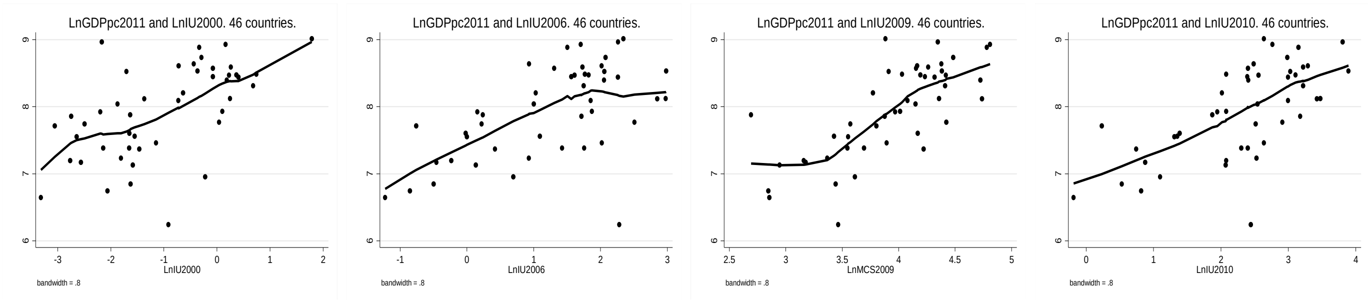

Fig. 5. Relationships between IU in 2000, 2006, 2009, 2010 and GDP PPP per capita in 2011. Non-parametric plots. Specification for 46 countries.

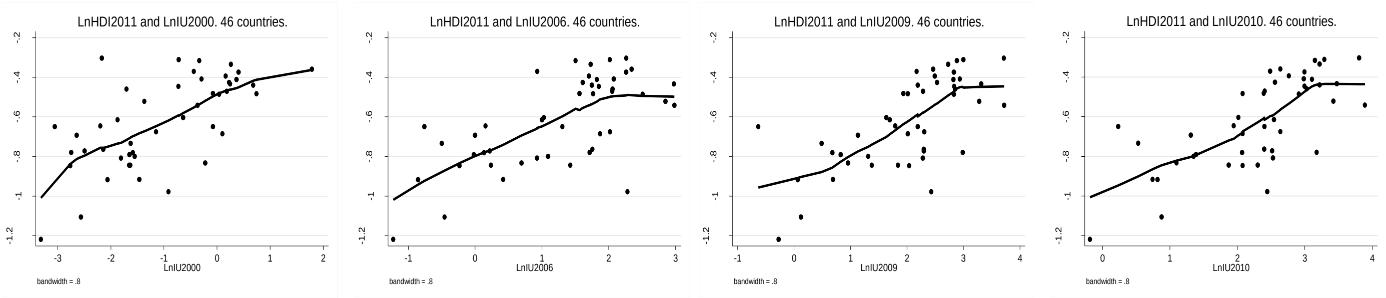

Fig. 6. Relationships between IU in 2000, 2006, 2009, 2010 and HDI in 2011. Non-parametric plots. Specification for 46 countries.

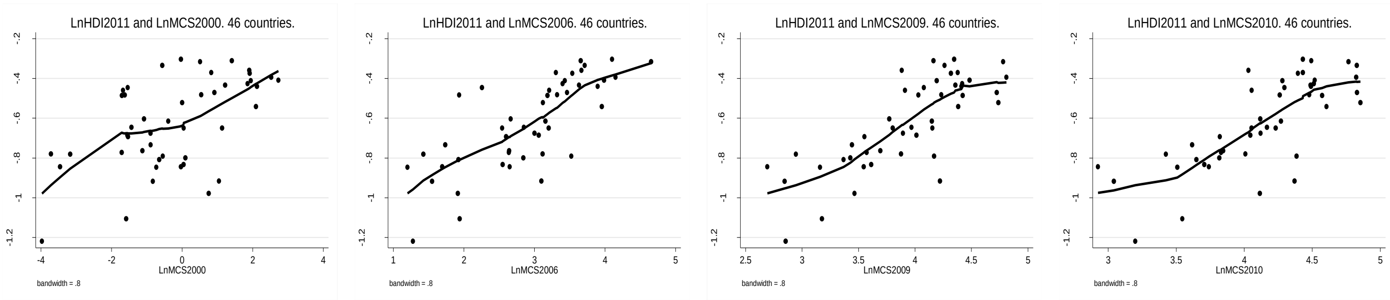

Fig. 7. Relationships between MCS in 2000, 2006, 2009, 2010 and HDI in 2011. Non-parametric plots. Specification for 46 countries.

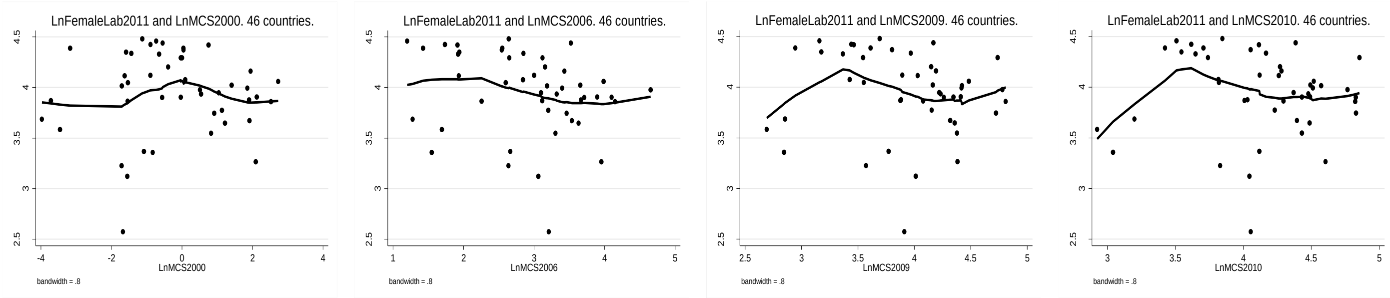

Fig. 8. Relationships between MCS in 2000, 2006, 2009, 2010 and FLP in 2011. Non-parametric plots. Specification for 46 countries.

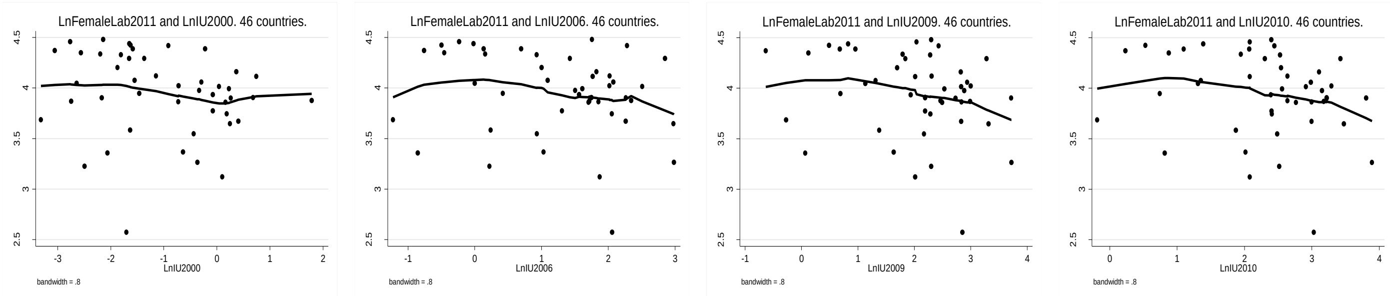

Fig. 9. Relationships between IU in 2000, 2006, 2009, 2010 and FLP in 2011. Non-parametric plots. Specification for 46 countries.

On plots, each dot corresponds with particular country, while the lines drawn in figures present non-parametric graphical approximation smoothing[16]. However the graphical evidence is scattered, the approximation lines are positively sloped and consistent with statistically significant relationships between plotted variables. This occurs in each case when $MCS_{i,y}$ /$IU_{i,y}$ and $GDPPPPpc_{i,y}$ is considered (including time lags for regressors) for $MCS_{i,y}$ /$IU_{i,y}$ *versus* $HDI_{i,y}$.The impression form plots in Figures 11-12 ($MCS_{i,y}$ and $IU_{i,y}$ *versus* $FLP_{i,y}$) yield the relationship to be rather negative, or poor positive, relationships.

The above empirical evidence clearly shows that level of adoption of new technologies (mobile cellular phones and Internet) correlates strongly and positively with economic growth and development. The results also claim that many of the least developed countries managed to make huge progress on development paths. Nevertheless, not all countries economic performance was evenly good, but we need to confront it with the fact that in almost each of the 46 studied countries the diffusion of ICTs was unprecedentedly dynamic. This provides substantial background for further growth boosting. For developing nations, new technologies can be important drivers of social, political and economic changes. Adoption of ICTs creates better conditions for education and skills improvement, let us to overcome barriers for disadvantaged groups empowerment and tap global market of goods and services. ICTs enhance shifts from traditional (usually agricultural) to modern forms of running business, letting countries to get more industrialized and create service-based economy. Above all, new technologies allow for declines of asymmetries, and by eliminating one of market failure, they i.g. better engagement in labour market, lead for job creation, foster national competition among producers, create friendly-environment for "going abroad" and starting trading internationally.
Surely all these are importantly reliant on national policies which should be designed as "pro-poor" providing legal conditions for full and effective use of new technologies. Individual country`s

[16] LOWESS – Locally Weighted Scatterplot Smootning.

development strategy can both provoke or hindrance entering sustainable development paths which might be initiated by adoption of information and communication technologies.
However, the analysis outcomes are as previously expected, we suppose that the evidence might not be robust. Final results are probably highly sensitive for exclusion or inclusion of outliers. The time horizon and number of countries included in the sample also are of crucial importance. We need to remember that the analyzed period of 2000-2011 is highly unique from historical perspective. In these 11 years, the rates of adoption of new technologies (especially mobile telephony) were extraordinarily high, and such dynamic changes are definitely unprecedented. That is why, taking into account the complexity of structural changes in national economies, we are not fully convinced on drawing rigid conclusions on wide long-term macroeconomic regularities in growth and development conditioned by diffusion on information and communication technologies.
Existence of dynamic links between technological progress and growth and development surely cannot be neglected, however we claim that these links are rather two-way, instead of going into one fixed direction. The latter might results in revealing of reverse-causalities between ICTs and growth, and what is even more these interactions can be determined by external factors endowing or fostering positive impulses for economic development.

7 Final conclusions.

In the unique period of 2000-2011, unprecedentedly dynamic of new information and communication technologies took place in each of the studies low and lower-middle-income countries. For many countries we have discovered that ICTs diffusion process – especially with respect to the variable $MCS_{i,y}$ – could be approximated by complete theoretical S-shaped trajectory. Such pervasive changes are mainly enabled by two crucial issues. Firstly, unique features of ICTs as development tools to spread at high pace and at low cost across countries and which are easy to imitate, and secondly – high ability of analyzed societies to assimilate new technologies. For the variable explaining the usage of Internet – $IU_{i,y}$, it is reported that most of countries are located in the early phase of diffusion process, however estimated average annual growth rates are pretty high. For $FTL_{i,y}$ the S-shaped curve was not

revealed and changes in fixed telephony were relatively poor. Additionally, we have identified the quantitative links between levels of ICTs adoption and economic growth ($GDPPPPpc_{i,y}$), economic development ($HDI_{i,y}$) and female labour participation ($FLP_{i,y}$). Implying different time lags for estimates, we generally found that there exist strong and positive links between ICTs adoption and economic growth and development. Such determination was not confirmed in case of $FLP_{i,y}$ regardless assumed time lags.
Clearly, the process of new technologies diffusion is fully accounted for the nature of them. Certain features of ICTs, absorptive capacities of society, knowledge and skills, information asymmetries, channels of diffusion and further adoption, state policies – all these highly condition diffusion rates, creating friendly environment for technology diffusion or – reversely – posing barriers to the process. Despite the above, the technology diffusion can be described as a long-run process, which results in broad spread of different kinds of innovations. It is widely agreed that the process enhances deep changes in economic structures, fosters economic growth and development, contributing to overall welfare of societies. All these accelerate least developed countries transformation changing then into dynamic economies. Regardless all the mentioned facts, it is important to keep in mind the fact that information and communication technologies` impact on economies` performance is claimed to exhibit in the long-run perspective and – in addition – their real impact is limited and hardly quantifiable, while the remarkable impact of ICTs on developing countries can only be confirmed when is converted into human development.

References:

1. Abramovitz M. (1986), Catching up, forging ahead, and falling behind, Journal of Economic History, Vol.46, Issue 2, pp.385-406
2. Abramowitz M. (1994), Catch-up and convergence in the postwar growth boom and after, in Baumol W., Nelson R, Wolff E., Convergence and productivity: cross-national studies and historical evidence, Oxford University Press, pp.86-125
3. Acemoglu D., Aghion P., Zilibotti F. (2006), Distance to frontier, selection and economic growth, Journal of European Economic Association 4(1), pp.37-74
4. Aghion, P., Durlauf S.N. (2008), Handbook of Economic Growth Volume 1A, Elsevier.
5. Aghion, P. and Howitt, P. (1992). A model of growth through creative destruction. Econometrica 60 (March), pp. 323-351.

6. Amable B. (1993), Catching-up and convergence: a model of cumulative growth, International Review of Applied Economics, vol.7, no.1, pp.1-25
7. Akpan, P.I. (2010). Basic-needs to globalization: are ICTs the missing link?. *Information Technology for Development*, 10:4, pp.261-274.
8. Anand. S, Sen, A.K. (1996). Sustainable human development: concepts and priorities. *Office of Development Studies Discussion Paper*, No.1, UNDP, New York.
9. Baliamoune-Lutz, M. (2003). An analysis of the determinants and effects of ICT diffusion in developing countries. *Information Technology for Development* 10 (2003), pp.151-169.
10. Baraldi, A.L. (2012). The size of the critical mass as a function of the strength of network externalities: a mobile telephone estimation. *Economics of Innovation and New Technology*, 21:4, pp. 373-396.
11. Baumol W. (1986), Productivity growth, convergence, and welfare: what the long-run data show, American Economic Review, vol.76, pp.1072-1084
12. Baumol, W.J. (1989). Reflections on Modern Economics: Review". *Cambridge Journal of Economics*, Oxford University Press, vol. 13(2), pages 353-58
13. Barro J.R. (2001), Human capital and growth, American Economic Review, No.91
14. Billon, M., Lera-Lopez, F., Marco, R. (2010). Differences in digitalization levels: a multivariate analysis studying the global digital divide. *Review of World Economy* (2010), 146, pp. 39-73.
15. Bousquet, A., and M. Ivaldi. (1997). Optimal pricing of telephone usage: An econometric implementation. *Information Economics and Policy* 9: 219–39.
16. Cabral, L. (2006). Equilibrium, epidemic and catastrophe: Diffusion of innovations with network effects. In *New frontiers in the economics of innovation and new technology: Essays in honor of Paul David*, ed. C. Antonelli, B. Hall, D. Foray and E. Steinmueller, 427–37. London: Edward Elgar.
17. Castellaci F. (2002), Technology gap and cumulative growth: models and outcomes, International Review of Applied Economics, 16 (3), pp. 333-346
18. Castellacci F. (2011), Closing the technology gap?, Review of Development Economics, 15(1), pp.189-197
19. Castellacci F. (2006), Convergence and divergence among technology clubs, DRUID Working Paper No. 06-21
20. Castellacci F. (2008), Technology clubs, technology gaps and growth trajectories, Structural Changes and Economic Dynamics 19(2008), pp.301-314
21. Castellaci F., Archibugi D. (2008), The technology clubs: the distribution of knowledge across nations, Research Policy 37
22. Chong, A., Micco, A. (2003). The Internet and the ability to innovate in Latin America. *Emerging Markets Review* 4, 53-72.
23. Comín, D., Hobijn, B. (2003). Cross-Country Technology Adoption: Making the Theories Face the Facts. *Paper prepared for the Carnegie Rochester Conference on Public Policy*.
24. David, P. (1990). The dynamo and the computer: an historical perspective on the modern Productivity Paradox. *The American Economic Review*, Papers and Proceedings of the Hundred and Second Annual Meeting of the American Economic Association, Vol. 80, No.2, May 1990, pp.355-361.
25. Darwin, C. (1859). The origin of species. John Murray, London.
26. Dasgupta, P., Stoneman, P. (2005). Economic Policy and Technological Performance". Cambridge University Press
27. Dasgupta, P., Weale, M. (1992). On measuring quality of life. *World Development*, 20, pp.119-131.
28. Davies, S. (1979). The diffusion of process innovation. Cambridge University Press.

29. De Guio, R., Kucharavy, D. (2007). Application of S-shaped curves. Published in "*TRIZ-Future Conference 2007: Current Scientific and Industrial Reality*", Frankfurt 2007.
30. Desai, M. (1991). Human development, concepts and measurement. *European Economic Review*, 35, pp.350-357.
31. Economides, N., and Himmelberg, C. (1995). Critical mass and network evolution in telecommunications. In G. Brock (Ed.), Toward a competitive telecommunications industry: Selected papers from the 1994 telecommunications policy research conference (pp. 31–42), University of Maryland, College Park, MD.
32. Estache, A., Manacorda, M., Valletti, T. M. (2002). Telecommunications, Reform, Access Regulation, and Internet Adoption in Latin America. *Economía*, Volume 2, Spring.
33. Fagerberg J. (1994), Technology and international differences in growth rates, Journal of Economic Literature 32, pp.1147-1175
34. Gancia G., Zilibotti F. (2009), Technological change and the wealth of nations, Annual Review of Economics, Vol.1
35. Geroski, P.A., (2000). Models of technology diffusion. *Research Policy* 29 (2000), pp.603-625
36. Gerschenkron, A. (1962). Economic backwardness in economic perspective. Belknap Press
37. Grandville de la O. (2009), Economic growth. A unified approach, Cambrigde Univeristy Press
38. Gilhooly, D. (2005). Innovation and investment: information and communication technologies and Millennium Development Goals. Report prepared for the *United Nations ICT Task Force* in Support of the Science, Technology & Innovation Task Force of the United Nations Millennium Project, 2005.
39. Goldfarb A., Prince, J. (2008). Internet adoption and usage patterns are different: implications for the digital divide. *Information Economics and Policy* 20 (2008), pp.2-15.
40. Gray, V. (1973). Innovation in the States. A Diffusion Study. *The American Political Science Review*, Vol. 67, No. 4, p.1174-1185.
41. Grazzi, M., Vergara, S. (2008). What drives ICT diffusion in developing countries? Evidence from Paraguay. Division of Production, Productivity and Management, CEPAL, United Nations.
42. Griliches, Z. (1957). Hybrid corn: an exploration in the economics of technological change. *Econometrica*, vol. 25, pp.501-522.
43. Grossman, G.M. and Helpman, E. (1991). *Innovation and growth in the global economy*. Cambridge MIT Press.
44. Hobijn, B., Comin, D. (2003). Cross-country technology adoption: making the theories face the facts. *Journal of Monetary Economics* 51(2003), pp.39-83.
45. James J. (2003), Bridging the global digital divide, Edward Elgar
46. Jovanovic, B., Lach, S. (1989). Entry, Exit, and Diffusion with Learning by Doing. *American Economic Review*, vol. 79, No. 4, September, pp. 690-699.
47. Karshenas, M., Stoneman, P. (1995). Technological diffusion. In *Handbook of Economic of Innovation and Technological Change* (Stoneman ed.). Blackwell. Cambridge.
48. Katz, M.L., and Shapiro, C. (1985). Network externalities, competition and compatibility. *The American Economic Review*, 75(3), 424–440.
49. Kim, H.-S., and N. Kwon. 2003. The advantage of network size in acquiring new subscribers: A conditional logit analysis of the Korean mobile telephone market. *Information Economics and Policy* 15: 17–33.
50. Klobas, J. E., Clyde, L.A. (1998). Learning to use the internet in a developing country: validation of a user model. *Libri,* Vol. 48, pp. 163-175.

51. Kucharavy, D. , Guio de, P. (2008). Logistic substitution model and technological forecasting. *TRIZ Future 2008* – Synthesis in Innovation.
52. Kyem, P.A., LeMaire, P.K. (2006). Transforming recent gains in the digital divide into digital opportunities: Africa and the boom in mobile phone subscription. *The Electronic J. Inf. Syst. Dev. Countries, EJISDC*, 28(5): 1-160.
53. Landes D. (1969), The unbound Prometeus, technological change and industrial development in Western Europe from 1750 to the present, Cambridge University Press
54. Lucas R. (1988), On the mechanics of economic development, Journal of Monetary Economics 22, pp.3-42
55. Mansfield, E. (1961). Technical Change and the Rate of Imitation. *Econometrica,* Vol. 29, No. 4, October, pp. 741-766.
56. Mansfield, E. (1968). The economics of technological change. W.W Norton&Company Inc., New York.
57. McGee, J. and Sammut, T.A. (2002). Network industries in the new economy. European Business Journal, 14(3), pp.116-131.
58. Meade, N., Islam, T. (2006). Modeling and forecasting the diffusion of innovation. *International Journal of Forecasting,* Vol. 22.
59. Metcalfe, J.S. (1988). The diffusion of innovation: an interpretive survey. In Technological Change and Economic Theory (ed. G. Dosi *et al.*). Pinter, London.
60. Modis, T. (2007). From my perspective. Strengths and weaknesses of S-curves. *Technology Forecasting & Social Change* 74 (2007) 866-972.
61. Myrdal G. (1957), Economic theory and underdeveloped regions, University Paperbacks METHUEN& CO LTD, London
62. Oliver, P., G. Marwell, and R. Teixeira. (1985). A Theory of Critical Mass: I. Interdependence, Group Heterogeneity, and the Production of Collective Action. *American Journal of Sociology* 9.3.
63. Perez, C. & Soete, L. (1988). Catching-up in Technology, Entry Barriers and Windows of Opportunity. In: Dosi,G. et al. (orgs.): Technical Change and Economic Theory. London: Pinter Publishers.
64. Phelps, E.S. (1965). Models of technical progress and the golden rule of research. *Review of Economic Studies* 33, pp. 133-145.
65. Rogers, M.E. (1962). Diffusion of innovation. The Free Press, London.
66. Röller, L.H., Waverman, L. (2001). Telecommunication Infrastructure and Economic Development: a simultaneous approach. *The American Economic Review*, Vol. 91, No.4, pp.909-923.
67. Romeo, A. (1977). The rate of imitation of a capital emdobied process innovation. *Economica*, 44, pp.63-69.
68. Romer, P. (1990). Endogenous technological change. *Journal of Political Economy* 98 (Oct): S71-S102.
69. Romero Ania, A., Alonso Neira, M.A., Blanco Jimenez, F.J., Fernandez-Cano, E.del A., (2012). Modelling and prediction of Internet diffusion in the African continent: the s-shaped Internet diffusion curve. *Proceedings 25th European Conference on Modelling and Simulation ECMS*, ed. Burczyński, T., Kołodziej, J., Byrski, A., Carvalho, M. (2012).
70. Roztocki, N., Weistroffer H.R. (2011). Information technology success factors and models in developing and emerging economies. *Information Technology for Development*,17:3, pp.163-167.
71. Shapiro, C. and Varian, H.R. (1998). *Information rules: a strategic guide to the network economy.* Cambridge, MA: Harvard Business School Press.

72. Shell, K. (1967). A model of innovative activity and capital accumulation. In Shell, K. (ed), *Essays on the theory of optimal economic growth*, MIT Press, Cambridge, pp. 67-85.
73. Soete, L. and Verspagen, B. (1993). Technology and growth: the complex dynamics of catching-up, falling behind and taking over. In Szirmai A. (ed): Explaining economic growth, Elsevier.
74. Quah D.T. (1996), Empirics for economic growth and convergence, European Economic Review 40, pp.1353-1375
75. Quah D.T. (1996), Galton`s fallacy and tests of the convergence hypothesis, Scandinavian Journal of Economics, 95, pp.427-443.
76. Quah D.T. (1996), Twin Peaks: growth and convergence in models of distribution dynamics, The Economic Journal Vol.106, No.437, pp.1045-1055.
77. Quibria, M. G., Ahmed, S.N., Tschang, T., Reyes-Macasaquit, M. L. (2002). Digital Divide: Determinants and Policies with Special Reference to Asia. *Economics and Research Department Working Paper* No. 27, Asia Development Bank, Manila.
78. Samiullah, Y., Rao, S. (2000). Role of ICTs in Urban and Rural Poverty Reduction. Paper prepared for MoEF-TERI-UNEP *Regional Workshop for Asia and Pacific on ICT and Environment*, May 2000, Delhi.
79. Sahin, I. (2006). Detailed review of Roger`s diffusion of innovation theory and educational technology-related studies based on Roger`s theory. *The Turkish Online Journal of Educational Technology* – TOJET April 2006, Vol. 5, Issue 2, Article 3.
80. Sarkar, J. (1998). Technological diffusion: alternative theories and historical evidence. *Journal of Economic Surveys* Vol.12, No.2
81. Schumpeter, J.A. (1934). Theory of economic development. Transaction Publishers
82. Schumpeter, J.A. (1947). The creative responses in economic history. *Journal of Economic History* 7, pp.149-159.
83. Sen, A.K. (1987). The standard of living. *Cambridge University Press*, Cambridge.
84. Shimogawa, S., Shinno, M., Saito, H. (2012). Structure of S-shaped growth in innovation diffusion. *Physical Review* E 85.056121(2012).
85. Streeten, P. (1981). First things first: meeting basic human needs in developing countries. *Oxford University Press*, Oxford.
86. Soete, L., Verspagen, B. (1993). Technology and growth: the complex dynamics of catching-up, falling behind and taking over. *Explaining Economic Growth*, Elsevier. Downloadable at: http://ideas.repec.org/p/ner/maastr/urnnbnnlui27-6312.html.
87. Stilianos, A. (2013). *Convergence clubs and spatial externalities. Model and applications of regional convergence in Europe*. Springer-Verlag.
88. Stoneman, P. (2001). The economics of technological diffusion. Blackwell. Oxford.
89. Udo, G., Bagchi, K.K., Kirs, P.J. (2008). Diffusion of ICT in developing countries: a qualitative differential analysis of four nations. *Journal of Global Information Technology Management* 11,1.
90. Uzawa, H. (1965). Optimum technical change in an aggregate model of economic growth. *International Economic Review* 6, pp. 18-31.
91. Verspagen, B. (1991). A New Empirical Approach to Catching Up or Falling Behind. *Structural Change and Economic Dynamics*, vol 2, No. 2, pp. 359-380.

Table 4. Statistical Appendix 1.

Basic ICTs statistics for low-income and lower-middle-income countries (46)
(Low-income countries are put in bolds). Years 2000 and 2011.

	Fixed-telephone subscriptions. Share of total population having access to fixed-telephone lines (%).			Mobile-cellular telephone subscriptions. Share of population with active mobile-cellular telephones (%).			Percentage of individuals using the Internet (%)		
	$FTL_{i,2000}$		FTL average annual exponential growth rate in 2000-2011 (approximations)	$MCS_{i,2000}$	$MCS_{i,2011}$	MCS average annual exponential growth rate in 2000-2011 (approximations)	$IU_{i,2000}$	$IU_{,i2011}$	IU average annual exponential growth rate in 2000-2011 (approximations)
Albania	4,97	10,54	7%	0,97	96,39	42%	0,11	49,00	55%
Armenia	17,34	18,63	1%	0,57	103,57	47%	1,30	32,00	29%
Bangladesh	**0,38**	**0,65**	**5%**	**0,22**	**56,06**	**51%**	**0,07**	**5,00**	**39%**
Belize	14,31	8,09	-4%	6,73	62,37	21%	5,96	15,19(a)	8%
Bolivia	6,15	8,71	3%	7,01	82,82	22%	1,44	30,00	28%
Burkina Faso	**0,43**	**0,83**	**6%**	**0,21**	**45,27**	**49%**	**0,08**	**3,00**	**33%**
Cambodia	**0,25**	**3,70**	**25%**	**1,05**	**96,17**	**41%**	**0,05**	**3,10**	**38%**
Cote d'Ivoire	1,59	1,33	-2%	2,85	86,06	31%	0,23	2,20	20%
Djibouti	1,33	2,04	4%	0,03	21,32	59%	0,19	7,00	33%
El Salvador	10,53	16,54	4%	12,52	133,54	22%	1,18	17,69	25%
Fiji	10,64	14,95	3%	6,78	83,72	23%	1,50	28,00	27%
Georgia	11,51	29,98	10%	4,41	98,73	29%	0,48	36,56	39%
Ghana	1,11	1,14	0%	0,68	84,78	44%	0,15	14,11	41%
Honduras	4,80	7,86	4%	2,50	103,97	34%	1,20	15,90	23%
India	3,08	2,63	-1%	0,34	72,00	49%	0,53	10,07	27%
Indonesia	3,12	15,94	15%	1,72	103,09	37%	0,93	18,00	27%
Kenya	**0,93**	**0,68**	**-3%**	**0,41**	**67,49**	**46%**	**0,32**	**28,00**	**41%**
Kyrgyzstan	**7,68**	**9,12**	**2%**	**0,18**	**113,98**	**59%**	**1,04**	**20,00**	**27%**
Lao PDR	0,77	1,71	7%	0,24	87,16	54%	0,11	9,00	40%
Lesotho	1,13	1,76	4%	1,10	56,17	36%	0,21	4,22	27%
Madagascar	**0,36**	**0,65**	**5%**	**0,41**	**40,65**	**42%**	**0,20**	**1,90**	**21%**
Malawi	**0,41**	**1,13**	**9%**	**0,44**	**25,69**	**37%**	**0,13**	**3,33**	**30%**
Mauritania	**0,72**	**2,04**	**10%**	**0,58**	**93,60**	**46%**	**0,19**	**4,50**	**29%**
Moldova	16,04	33,15	8%	3,82	104,38	31%	1,28	38,00	31%
Mongolia	4,87	6,70	3%	6,41	105,08	25%	1,26	20,00	25%
Morocco	4,95	11,05	7%	8,13	113,26	24%	0,69	51,00	39%
Nepal	**1,09**	**2,77**	**8%**	**0,04**	**43,81**	**63%**	**0,20**	**9,00**	**34%**
Niger	**0,18**	**0,53**	**10%**	**0,02**	**29,52**	**67%**	**0,04**	**1,30**	**33%**
Nigeria	0,45	0,44	0%	0,02	58,58	71%	0,06	28,43	55%
Pakistan	2,11	3,24	4%	0,21	61,61	52%	1,11(a)	9,00	19%
Paraguay	5,29	5,67	1%	15,36	99,40	17%	0,75	23,90	31%
Philippines	3,96	3,75	0%	8,35	99,30	23%	1,98	29,00	24%
Rwanda	**0,22**	**0,36**	**4%**	**0,48**	**40,63**	**40%**	**0,06**	**7,00**	**43%**
Sri Lanka	4,02	17,29	13%	2,25	87,78	33%	0,65	15,00	29%
Swaziland	3,15	7,10	7%	3,26	71,79	27%	0,93	18,13	27%
Syria	10,48	20,87	6%	0,19	63,00	53%	0,18	22,50	44%
Tanzania	**0,51**	**0,35**	**-3%**	**0,32**	**55,53**	**47%**	**0,12**	**12,00**	**42%**
Togo	**0,89**	**3,90**	**13%**	**1,04**	**50,45**	**35%**	**0,80**	**3,50**	**13%**
Uganda	**0,25**	**1,35**	**15%**	**0,52**	**48,38**	**41%**	**0,16**	**13,01**	**40%**
Ukraine	21,18	27,74	3%	0,52	121,60	39%	0,72	30,60	34%
Uzbekistan	6,71	6,57	0%	0,22	86,71	55%	0,48	30,20	38%
Vanuatu	3,59	2,54	-3%	0,20	55,76	51%	2,11	9,06(a)	13%
Vietnam	3,28	11,58	12%	1,02	144,94	45%	0,25	35,07	45%
Yemen	1,96	4,33	7%	0,18	47,05	51%	0,08	14,91	47%
Zambia	0,82	0,64	-2%	0,97	60,59	38%	0,19	11,50	37%
Zimbabwe	**1,99**	**2,79**	**3%**	**2,13**	**72,13**	**32%**	**0,40**	**15,70**	**33%**

Source: Own estimates based on data derived from World Telecommunication/ICT Indicators Database 2012 (16th edition) and World Development Indicators 2012. (a) – estimates based on time-trend exponential growth rates (author`s own calculations).

Table 5. Statistical Appendix 2.

GDP PPP *per capita*, Human Development Index, Female Labour Participation.
Low and lower-middle-income countries (46).
(Low-income countries are put in bolds). Years 2000 and 2011.

	Gross Domestic Product (PPP) per capita			Human Development Index			Femal Labour Participation [%]		
	GDP PPP $pc_{i,2000}$	GDP PPP $pc_{i,2011}$	GDP PPP pc annual exponential growth rate	$HDI_{i,2000}$	$HDI_{i,2011}$	$HDI_{i,2011} - HDI_{i,2000}$ [change in %pp]	FLP-$_{i,2000}$	$FLP_{,i2011}$	$FLP_{i,2011} - FLP_{i,2000}$ [change in %pp.]
Albania	3841	7848	6,5%	0,71[17]	0,739	2,78	50,9	49,6	-1,3
Armenia	1926	5392	9,4%	0,643	0,716	7,3	57,7	49,4	-8,3
Bangladesh	918	1909	6,7%	0,422	0,5	7,8	54,3	57,2	2,90
Belize	5814	8219	3,1%	0,668	0,699	3,1	40,2	48,3	8,09
Bolivia	3102	4793	4,0%	0,612	0,663	5,1	59,6	64,1	4,5
Burkina Faso	814	1302	4,3%	0,325	0,331	0,6	77,3	77,5	0,19
Cambodia	908	2239	8,2%	0,438	0,523	8,47	76,5	79,2	2,66
Cote d'Ivoire	1600	1590	-0,1%	0,374	0,400	2,6	48,8	51,8	3
Djibouti	1733	2641	3,8%	0,445	0,430	-1,5	31,4	36	4,6
El Salvador	5243	7550	3,3%	0,619	0,674	5,57	44,7	47,4	2,7
Fiji	3404	4643	2,8%	0,668	0,688	2,03	39,1	39,3	0,2
Georgia	2230	5491	8,2%	0,70[18]7	0,733	2,6	54,7	55,8	1,09
Ghana	1443	3113	7,0%	0,451	0,541	8,9	72,6	66,9	-5,7
Honduras	2996	4444	3,6%	0,569	0,625	5,5	44,4	42,3	-2,1
India	1534	3663	7,9%	0,461	0,547	8,5	34,3	29	-5,3
Indonesia	2429	4666	5,9%	0,543	0,617	7,4	50,4	51,2	0,79
Kenya	1217	1741	3,3%	0,443	0,509	6,6	63,1	61,5	-1,6
Kyrgyzstan	1337	2372	5,2%	0,577	0,615	3,8	56,2	55,5	-0,7
Lao PDR	1199	2768	7,6%	0,448	0,524	7,6	78,9	76,5	-2,4
Lesotho	1000	1918	5,9%	0,427	0,450	2,2	67,6	58,9	-8,7
Madagascar	763	944	1,9%	0,427	0,480	5,3	84	83,4	-0,6
Malawi	558	851	3,8%	0,343	0,400	5,6	23,1	28,7	5,6
Mauritania	1382	2008	3,4%	0,410	0,453	4,3	77,2	84,8	7,6
Moldova	1482	3373	7,5%	0,586	0,649	6,2	55,4	38,4	-17
Mongolia	2039	4770	7,7%	0,555	0,653	9,8	55,7	54,3	-1,4
Morocco	2667	5080	5,9%	0,507	0,582	7,4	29	26,2	-2,8
Nepal	791	1249	4,2%	0,398	0,458	6,0	81,9	80,4	-1,5
Niger	489	771	4,1%	0,229	0,295	6,6	38	39,9	1,9
Nigeria	1130	2582	7,5%	0,462	0,459	-0,3	44,8	47,9	3,1
Pakistan	1780	2786	4,1%	0,436	0,504	6,8	16	22,7	6,7
Paraguay	4060	6224	3,9%	0,612	0,665	5,3	51	57,9	6,9
Philippines	2442	4080	4,7%	0,602	0,644	4,2	48,7	49,7	1
Rwanda	567	1334	7,8%	0,313	0,429	11,6	86,4	86,4	0
Sri Lanka	2771	5664	6,5%	0,633	0,691	5,7	37,2	34,7	-2,5
Swaziland	3567	5301	3,6%	0,492	0,522	2,9	42,7	43,6	0,89
Syria	3351	5041[19]	3,7%	0,583	0,632	4,8	20,4	13,1	-7,3
Tanzania	781	1610	6,6%	0,364	0,466	10,1	87	88,2	1,19
Togo	786	1048	2,6%	0,408	0,435	2,6	76	80,4	4,4
Uganda	771	1385	5,3%	0,372	0,446	7,3	80,7	76	-4,7
Ukraine	3206	7222	7,4%	0,669	0,729	5,9	51,8	53,3	1,5
Uzbekistan	1417	3273	7,6%	0,611[20]	0,641	2,9	47,5	47,7	0,2
Vanuatu	3629	4844	2,6%	0,542	0,617	7,5	70	61,3	-8,7
Vietnam	1424	3359	7,8%	0,528	0,593	6,5	74,3	73,2	-1,1
Yemen	2019	2307	1,2%	0,374	0,462	8,7	22,1	25,2	3,1
Zambia	909	1611	5,2%	0,371	0,430	5,9	75,1	73,2	-1,9
Zimbabwe	866	515	-4,7%	0,372	0,376	0,4	68,7	83	14,3

Source: World Development Indicators (April 2013), Human Development Report 2013, with author`s own estimates.

17 Data from 2005.

18 Data from 2005.

19 Author`s estimates based on time-trend.

20 Data for 2005.

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